BRICKWORK TESTS: REPORT ON THE FIRST SERIES OF EXPERIMENTS.

By William C. Street [*F.*] and Max. Clarke [*A.*].

Read at the General Meeting, Monday, 30th March 1896, and, with the notes and statistics which follow, registered at Stationers' Hall as the property of the Royal Institute.

WE have to lay before the Institute an account of the proceedings of the Science Standing Committee, so far as they have at present reached, in the series of experiments which the Committee have undertaken for the purpose of ascertaining the amount of resistance possessed by brickwork under great crushing loads.

The subject may be thought to be one that comes more within the province of the engineer than of the architect; but, not being able to find any reliable data, and the text-books and authorities differing so widely, the committee considered it desirable to institute some systematic experiments whereby the average and relative strengths of bricks and brickwork of different varieties could be determined.

The scheme was primarily submitted to the Science Committee by Mr. H. W. Burrows, and by them referred to a sub committee, consisting of Messrs. Burrows, Faija, and Street. Since then Mr. Faija has died, and Professor Unwin and Mr. Max. Clarke have been added to the sub-committee.

The experiments finally decided upon were to be confined to the following varieties, as affording types of the several kinds most generally employed, viz.:—

1. London stocks.
2. Gault.
3. Leicester red.
4. Staffordshire blue.

Two piers of each kind, 6 feet high and 18 inches square, were to be built, both in lime mortar and in cement, for crushing at the end of three months, and a similar number for crushing at the end of nine months.

The reason for deciding upon having tests at two different periods was to ascertain what additional strength the brickwork gained in six months, as this is of importance, considering the great rapidity with which brick buildings are now run up, and sometimes loaded with great weights while the brickwork is quite green and very little of the mortar set.

It is now almost ancient history to relate how little response there was to the appeal for subscriptions to defray the necessary expenses; and the matter would probably have been allowed to drop had not Sir William Arrol, at the instance of Professor Unwin, generously come forward and placed at the disposal of the committee a very powerful hydraulic press, together with a large and massive testing-machine made expressly for the committee's purpose.

The next difficulty was to find a site of the necessary extent, and near to an hydraulic main. This was overcome by the kindness of the London and India Docks Joint Committee, who, through their chief engineer (Mr. H. F. Donaldson), placed at the disposal of the committee a vacant piece of ground in front of the engineer's office at the West India Docks,

and close to the hydraulic engine-house, from which water at a pressure of 700 pounds to the square inch was available.

These initial difficulties being overcome, the work of building the experimental piers commenced on the 24th July 1895, and was finished on the 13th August. The piers are built upon a temporary line of rails about 140 feet in length, and laid to a 16-inch gauge. In the centre of the line of rails Sir William Arrol's testing-machine was erected in the course of the autumn, so as to be ready for the first testing in December. A description of the machine, by Mr. J. E. Tuit, is given in an appendix [pp. 352–53].

The piers are built upon wrought-iron plates, 2′ 0″ × 2′ 6″ × ½″, which are placed upon the rails one foot apart, and have two holes drilled in the end nearest the testing-machine, by means of which they are drawn along the rails to the machine.

The bricks, lime, and sand were bought from Messrs. Cliff & Sons, and are such as would be supplied to any builder in the ordinary way. The Portland cement was kindly given by Messrs. J. Bazley White & Brothers, Limited, and is of ordinary quality. Samples of the

Pier No. 1. London Stocks from Sittingbourne, in Lime Mortar.*

6′ 0″ high, 18″ × 18″; sectional area 2·25 sq. ft.
Built 7th August; crushed 9th December. Age 17·7 weeks.

A

This pier was crushed at a preliminary trial of the machine on the 9th December, and the experiment was altogether unsatisfactory, except as affording knowledge of what was required for the efficient conduct of the remainder.

The pressure water was admitted into the ram too rapidly, and the pier was crushed immediately, and before any observations could be made. Also the divisions in the gauge recording the pressure were so small as not to admit any reliable registration of the results.

The maximum pressure on the gauge appeared to be about 125 lb. per sq. in., but it was very sudden and very uncertain.

The sketch, A, by Mr. Max. Clarke, shows something like the state of the pier immediately after crushing.

Large fractures appeared on two sides of the pier extending to within two courses of the bottom, these two courses remaining sound.

In the interval between the 9th and 13th December other pressure gauges were procured and fixed, and the valve on the pipe from the hydraulic main so arranged that the pressure could be admitted very slowly.

Pier No. 2. London Stocks from Sittingbourne, in Lime Mortar.

6′ 0″ high, 18″ × 18″; sectional area 2·25 sq. ft.
Built 7th August; crushed 13th December. Age 18·3 weeks.

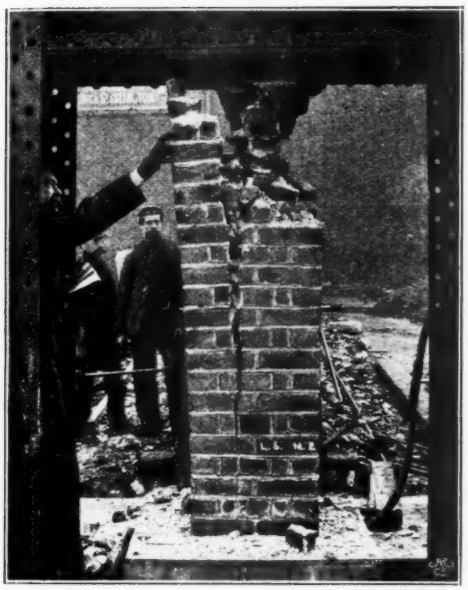
Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
—	30	9·42	4·18	—	Signs of the mortar in the interior of pier crumbling, and the pier began to bulge two courses from the top.
—	43	15·45	6·87	—	Mortar dropping out from joints near the top.
—	55	21·02	9·34	—	Pier cracked on two sides, the cracks extending downwards five or six courses in continuous lines.
—	60	23·34	10·41	—	Pier bulged, split all down, and fell.

The chief crack was through all courses, except the bottom one, vertical, and at 7 inches from an angle of the pier—*i.e.* at the line of closers.

A well-formed pyramid adhered to the underside of the top girder of the machine after the loose débris fell, showing normal type of failure.

The mortar was not fully set.

* These tables have been prepared by Mr. Street, from notes taken by himself and Messrs. Max. Clarke, Dicksee, Garbutt, and Solomon.

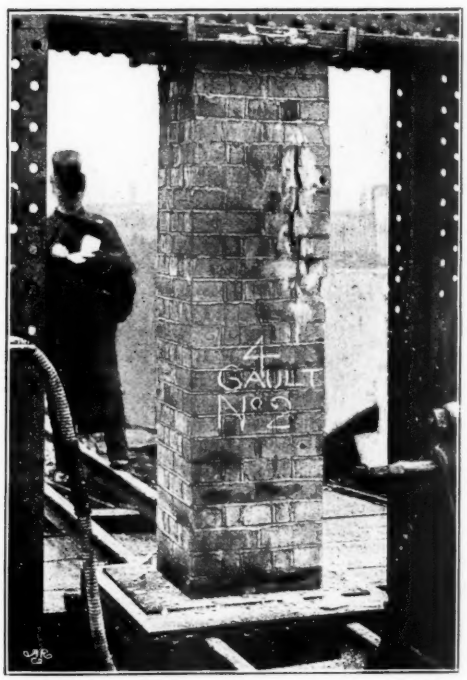


T. H. H.

FIG. 1.—PIER NO. 2, AFTER COMPRESSION.

T. H. H.

FIG. 3.—PIER NO. 4, AFTER COMPRESSION.



W. W.

FIG. 2.—PIER NO. 4. GAUGE AT 11Q

T. H. H.

FIG. 4.—PIER NO. 5, AFTER COMPRESSION

bricks and of the two kinds of mortar have been tested by Professor Unwin at the Central Technical College, and the results, with notes on the same, are given in appendices by Professor Unwin [pp. 348–52].

The piers on one side of the testing-machine are in Portland cement mortar, and on the other in grey lime mortar. The cement mortar was mixed by measure in the proportion of one of cement to four of washed river sand, and the lime mortar one to two. The brickwork starts upon a bed of mortar of the thickness of an ordinary joint, and rises, as nearly as possible, four courses to the foot. The bond is the same as shown in Rivington's text-book, and is the ordinary way of building an 18-inch pier. It has a fault in permitting a small rectangular vertical joint, $2\frac{1}{4}'' \times 2\frac{1}{4}''$, throughout the height of the pier, in each of the angles; but it was

Pier No. 3. Gault Bricks from Burham, Kent, in Lime Mortar.

6′ 0″ high and $18\frac{1}{4}'' \times 18\frac{1}{2}''$; sectional area 2·344 sq. ft.
Built 7th August; crushed 13th December. Age 18·3 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
	30	9·42	4·00		One crack through one brick in top course only. This was probably due to unequal distribution of pressure, the underside of top girder of machine being concave to the extent of $\frac{1}{2}$ inch. This was corrected before the next experiments (17th December) by a plate of lead cast to fit the concavity.
—	35	11·74	5·00	—	Bricks spalling slightly, and mortar inside the pier audibly crumbling.
—	45	16·38	6·98	—	Mortar dropping out of joints at top of pier.
—	60	23·34	9·95	—	The bricks in one corner commenced cracking, and the whole pier bulging very slightly.
—	78	31·69	13·51	—	Mortar continued dropping, and general signs of giving.
—	112	47·46	20·24	—	Pier cracking badly.
—	120	51·18	21·82	—	Went all over. Crushed fairly all through, nearly every brick being broken to within five courses of bottom. Bulged on all sides at once, and evenly.

*** Mortar properly set for about $1\frac{1}{2}''$ from surface only.

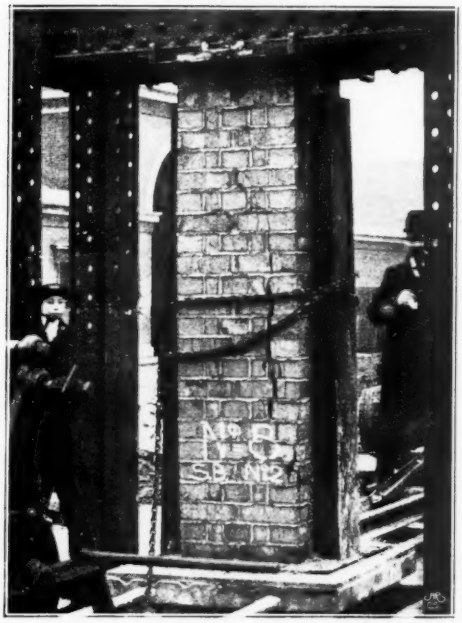
Pier No. 4. Gault Bricks from Burham, Kent, in Lime Mortar.

6′ 0″ high, $18\frac{1}{4}'' \times 18\frac{1}{4}''$; sectional area 2·281 sq. ft.
Built 7th August; crushed 17th December. Age 18·8 weeks.

*** This pier had on one side some slight frost cracks, starting three courses from top and extending to three courses.

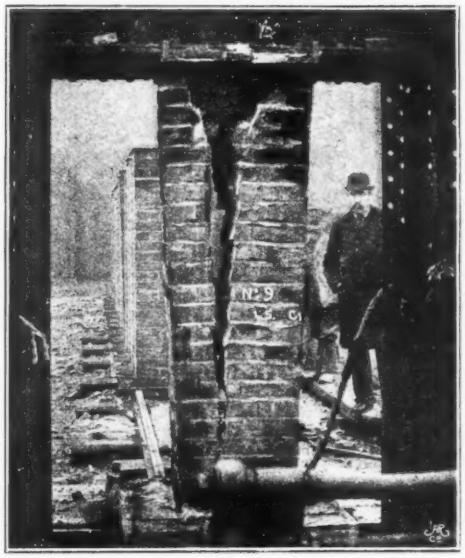
Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
10.46	10	0·14	—	—	Took its bearing.
—	30	9·42	4·12	—	Slight sounds of internal cracking or crumbling, audible on placing the ear close against pier.
—	40	14·06	6·16	—	One brick cracked at half height of pier.
10.51	55	21·02	9·21	—	Cracks visible on two sides, apparent continuations of frost cracks. Slight falling of mortar.
$10.54\frac{1}{2}$	80	32·62	14·30	—	Cracks in bricks themselves, and mortar bulging out badly fifth course from bottom, and a bad failure in third course from top at corner.
—	90	37·25	16·15	—	Cracking badly.
—	105	44·22	19·38	—	Cracks opening, the worst fissure $\frac{1}{4}''$ wide.
11.0	110	46·54	20·40	—	Bursting out at top.
—	115	48·86	21·42	$\frac{7}{16}''$	Considerable spalling of bricks at top; many small cracks near top, but very few below centre.
11.3	118	50·25	22·03	—	Collapse, pier spread in all directions fairly evenly; final bulging was greatest about two-thirds height from bottom.

*** Mortar in this pier was of a brown colour for about $1\frac{1}{4}''$ to 2″ all round from face.



T. H. H.

FIG. 5.—PIER NO. 8: COMMENCING TO GIVE WAY UNDER COMPRESSION.



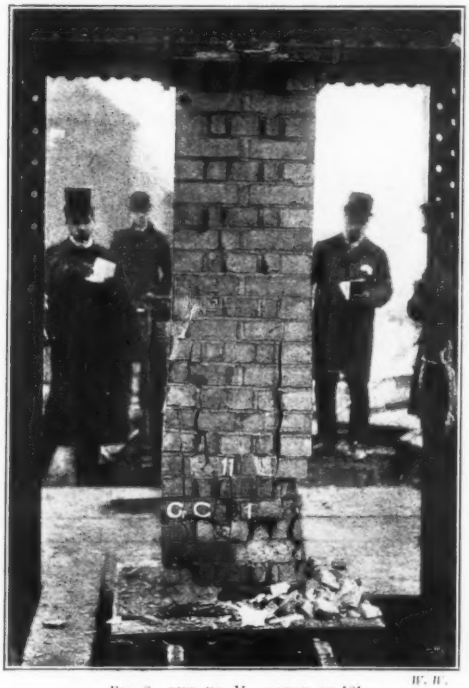
T. H. H.

FIG. 6.—PIER NO. 9, AFTER COMPRESSION.

*** The initials "T. H. H." and "W. W." attached to the illustrations are those respectively of Mr. T. H. Howe and Mr. W. Wonnacott [A.], who took the photographs from which the illustrations are reproduced.

W. W.

FIG. 7.—PIER NO. 11. GAUGE AT 98.



W. W.

FIG. 8.—PIER NO. 11. GAUGE AT 101.

thought better to keep to actual practice than to attempt a theoretically perfect bond. Each pier had the joints struck with a weathered joint as the work proceeded, and was finished with a layer of mortar, upon which a sheet of felt was laid to prevent the top courses deteriorating from heavy rain. The building of the piers was executed under the inspection and superintendence of Messrs. Max. Clarke, Hooper, and Street, and a record of progress was kept, so that the age of each pier at the time of testing could be ascertained. The labour was supplied by a large firm of contractors, and it is with regret that the committee have to state that, during the absence of members of the committee, the bricklayers, finding the Leicester red and the Staffordshire blue bricks very hard to cut,

Pier No. 5.—Leicester Red Bricks, from Elliston, near Leicester, in Lime Mortar.

6′ 1″ high, $18\frac{1}{8}$″ × $18\frac{1}{4}$″; sectional area 2·298 sq. ft.
Built 5th August; crushed 17th December. Age 19·1 weeks.

*** This pier had frost cracks through top three courses, three on one side, and one on another.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
11.26	7	—	—	—	Just bearing.
11.32	30	9·42	4·09	—	Slight internal cracking audible.
11.35	60	23·34	10·15	—	No signs of any outward crack or failure, but sounds of internal failure, audible by ear against pier.
11.36	85	34·94	15·20	—	Mortar dropping off very slightly from bottom joints.
—	95	39·58	17·22	—	Crack in brick, top course.
—	100	41·90	18·23	—	Slightly spalling, top course.
—	115	48·86	21·26	—	Mortar crushing out near bottom.
—	125	53·50	23·28	$\frac{1}{2}$″	Mortar steadily falling in small pieces.
—	134	57·67	25·09	$\frac{9}{16}$″	
—	145	62·78	27·31	—	Many fine cracks at bottom, a few at top.
11.42	150	65·10	28·32	—	Giving steadily, especially near bottom, but no crack more than $\frac{1}{16}$″ open. No continuous crack. Pressure shut off for two minutes, and gauge fell 5 lb.
11.45	158	68·81	29·93	—	On re-admitting pressure gauge rose to 158, when the pier gave way evenly.

*** A portion, eight courses high, remained of the southern face, but only part of three courses on the northern face; the southern face was the first to show signs of serious crippling, and was the one of which most remained after the final crippling.

Pier No. 6.—Leicester Red Bricks from Elliston, near Leicester, in Lime Mortar.

6′ 1″ high, $18\frac{1}{4}$″ × $18\frac{1}{4}$″; sectional area 2·313 sq. ft.
Built 9th August; crushed 17th December. Age 18·6 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
12.8	—	—	—	—	Top two courses on two sides slightly damaged by frost.
12.9$\frac{1}{4}$	8	—	—	—	Took bearing.
12.17	50	18·70	8·04	—	Slight indications of mortar inside crumbling.
12.18	70	27·98	12·09	—	Distinct internal crack.
—	90	37·26	16·11	—	Mortar falling from top joints.
—	105	44·22	19·11	—	Mortar dropping out from top joints, and a few single bricks cracked near top and bottom as the pressure gradually rose to 120.
12.21	145	62·78	27·14	$\frac{7}{8}$″	Mortar coming off face of joints, and several very slight cracks.
—	163	71·13	30·75	1″	Bricks bursting out from the third to the sixth course from the top.
—	167	72·98	21·55	—	Pier bulged and fell. The greatest bulging was near the middle. The five lowest courses were practically unshifted in position.

FIG. 9.—PIER NO. 11. GAUGE AT 103.

FIG. 11.—PIER NO. 12, AFTER COMPRESSION. FRONT VIEW.

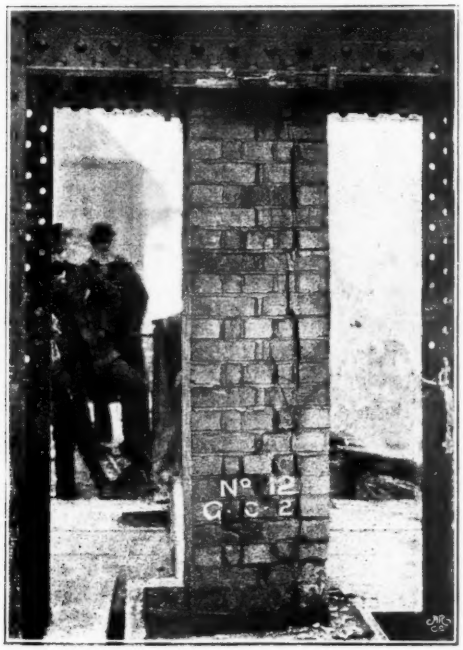


FIG. 10.—PIER NO. 12. GAUGE AT 97.

FIG. 12.—PIER NO. 12, AFTER COMPRESSION. BACK VIEW.

filled in a great portion of two piers with closers of London stocks. This quite destroyed the value of these piers, and has put the committee to the expense of building fresh piers to take

Pier No. 7 – Staffordshire Blue Bricks from Rowley Regis, in Lime Mortar.

6′ 0$\frac{3}{16}$″ high, 18$\frac{1}{8}$″ × 18$\frac{1}{8}$″; sectional area 2·281 sq. ft.
Built 9th August; crushed 17th December. Age 18·6 weeks.

*** This pier looked sound all over.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
1.39	10	–	–	–	Took bearing.
1.45	90	37·26	16·33	–	Sounds of mortar cracking.
—	120	51·18	22·43	–	Sharp crack heard, no visible crack, mortar falling slightly from joints about centre of pier.
—	130	55·82	24·03	$\frac{9}{16}$″	Mortar dropping occasionally, audible cracks (like tightening up a wooden screw).
—	150	65·10	28·54	–	Two bricks cracked near centre on eastern side.
—	152	66·02	28·94	$\frac{5}{8}$″	
—	160	69·74	30·57	—	Two bricks broken 4$\frac{1}{2}$″ from angle, in line with the closers, three courses high about centre of pier.
—	190	83·66	36·67	–	Faces of joints burst off nearly all over pier.
—	220	97·58	42·77	$\frac{15}{16}$″	Bricks cracked on northern face and mortar joints dropping out all over.
—	255	113·82	49·89	—	General disturbance of joints all over exterior.
—	265	118·46	51·93	—	Very audible cracks.
—	300	134·70	59·05	1$\frac{5}{16}$″	Many cracks on both sides about middle. Gauge fell and then pressure was allowed to stand (water cut off).
1.58	350	157·90	69·22	—	On pressure water being turned on, it went up to 350, when the sides bulged and the pier collapsed rather sharply. Cracks worst at lines of closers.

*** After failure portions remained on eastern side ten courses high; northern side, seven courses high; southern side, ten courses high.

Pier No. 8.– Staffordshire Blue Bricks, from Rowley Regis, in Lime Mortar.

6′ 0$\frac{3}{16}$″ high, 18″ × 18$\frac{1}{8}$″; sectional area 2·281 sq. ft.
Built 3rd August; crushed 17th December. Age 19·4 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
2.23	10	14		—	Took bearing.
—	90	37·26	16·33	—	No sign of failure anywhere.
—	115	48·86	21·42	–	Slight falling out of mortar joints.
—	120	51·18	22·43	–	Slight internal crack of brick.
—	130	55·82	24·03	—	Cracking audible on placing ear close to pier.
—	150	65·10	28·54		Sounds increased.
—	180 to	79·02	34·64	—	Mortar split off face of many joints all over.
—	190	83·66	36·67	—	
—	200	88·30	38·71	—	Mortar joints dropping out.
—	210	92·94	40·74	—	Mortar continually falling.
—	235	104·54	45·83	$\frac{13}{16}$″	Appreciable sounds of cracking.
—	260	116·14	50·91	—	Several small surface cracks.
—	285	127·74	56·00	—	Mortar falling out worse.
—	300	134·70	59·05	1″	Failing on the line of closers.
—	325	146·30	64·14	—	Cracks becoming more continuous all down the line of closers on each side.
—	375	169·50	74·31	—	Cracks worse, but none open $\frac{1}{16}$″.
—	400	181·10	79·39	—	Giving, splitting; gauge ran back to 375, then corners came out, *i.e.* pieces about 2″ long, at centre of height and bounded by the closers. Complete failure followed.

*** After the failure, parts of ten courses were left on northern side, less on other sides.

their place. This is an unpleasant admission to make, but, if the experiments are to be of any value, everything in connection with them must be told, and nothing concealed.

The testing of the piers commenced on the 9th December last, when the first pier, built with London stocks in lime mortar, was crushed in an experimental trial of the machine. On this occasion the pressure was applied much too suddenly, and the divisions on the gauge indicating the pressure were so small as not to admit of any reliable registration of the results. This trial, of which the records are of little value, enabled these defects to be ascertained and to be remedied. A better arrangement of valve, admitting the pressure very slowly, was obtained, and, at the request of Mr. Max. Clarke, a testing gauge, showing the pressures more minutely, was kindly lent to the committee by Messrs. W. & J. Fraser, of Commercial Road. The second meeting was on the 13th December, when piers Nos. 2 and 3 were crushed. (The results of all the crushings are given in the tabulated statements appended, pp. 334–344.) It was noticed on this occasion that the underside of the upper part of the testing frame was concave to the extent of about half an inch, and did not permit the equal distribution of the pressure upon the heads of the piers. In placing No. 2 in position the space between the head and the underside of the frame was packed with sheets of felt and small pieces of thin timber. With No. 3 pier this space was packed with two sheets of felt and one sheet of 7 lb. lead.

Pier No. 9.—London Stocks from Sittingbourne, in Cement Mortar.

6′ 0⅛″ high, 18″ × 18⅛; sectional area 2·266 sq. ft.
Built 25th July; crushed 20th December. Age 21·1 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
10.26	15	2·46	1·08	—	Bearing taken suddenly.
10.34	—	—	—	—	Pressure resumed.
10.37½	40	14·06	6·20	—	
10.38	45	16·38	7·22	—	Slight crack in top course.
10.39	50	18·70	8·25	—	Bricks spalling.
10.40	60	23·34	10·30	·07″	Cracks increasing, apparently due to unequal bedding.
10.41	70	27·98	12·34	—	Top two courses cracked, and crack extending downwards.
10.42	75	30·30	13·37	⅛″	
10.42½	80	32·62	14·39	·20″	Top two courses well crushed at corner. Crack ten courses down.
—	85	34·94	15·42	·25″	
10.44	88	36·33	16·03	—	Failed completely, pier split right down by closers.

Pier No. 10.—London Stocks from Sittingbourne, in Cement Mortar.

6′ 0¼″ high, 18¾″ × 18⅞″; sectional area 2·458 sq. ft.
Built 26th July; crushed 20th December. Age 21 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
11.12	11	·60	·24	—	Into bearing.
—	25	7·10	2·88	—	
11.16½	40	14·06	5·72	·10″	Slight crack in one brick at top corner.
11.17	45	16·38	6·66	·15″	
11.18½	50	18·70	7·60	·20″	
—	65	25·66	10·44	·22″	
11.21	70	27·98	11·38	·25″	
11.22	75	30·30	12·32	·30″	Failing, bottom course crushing.
—	80	32·62	13·27	·32″	
11.23	83	34·01	13·83	—	Failed completely.

After crushing No. 3 pier it was decided to adjourn the proceedings till Tuesday, 17th December, and that in the interval a mould should be taken of the underside of the upper part of the testing-frame, and a lead casting made to fit the concavity, which could be applied to the head of each pier when placing it in position in the machine.

The work was resumed on the 17th December, and in the interval the underside of the upper portion of the frame had been fitted with a plate of lead moulded to fit the concavity, and held in place by sheet iron and iron clips. On the head of each pier tested there was placed first a sheet of felt, and then a sheet of iron $\frac{1}{16}''$ thick, so that the pressure may be considered to be fairly well distributed. On this occasion piers Nos. 4, 5, 6, 7, and 8 were crushed, with the results noted in the Table. The tests of the piers in lime mortar which were intended for the first period being thus completed, and it being nearly 3 P.M., it was resolved to adjourn, and commence the crushing of the piers in cement mortar on Friday, 20th December, when

Pier No. 11.—Gault Bricks from Burham, Kent, in Cement Mortar.

6′ 0″ high, $18\frac{3}{8}'' \times 18\frac{1}{8}''$; sectional area 2·344 sq. ft.
Built 26th July; crushed 20th December. Age 21 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
12.2	10	·14	·06	—	Into bearing.
12.4½	30	9·42	4·00		
12.6	45	16·38	6·98	·07″	
12.7¼	60	23·34	9·95	·10″	
12.7½	65	25·66	10·94	—	Sounds of cracking.
12.8	70	27·98	11·93	—	Crack in bottom course.
12.8½	75	30·30	12·92	·15″	Ditto continuing upwards.
—	78	31·69	13·51	—	Ditto ditto.
—	80	32·62	13·91	—	Slight dropping of cement.
12.10	85	34·94	14·90	—	Spall two courses from bottom, northern side.
12.10½	90	37·26	15·89	·20″	Spalling going on.
12·11	95	39·58	16·88	·25″	Eastern side showing signs of failure.
12.12	100	41·90	17·87	—	Serious failing at bottom course.
12.13	101	42·16	18·07	—	Split from bottom and collapsed, the top for about five courses being uninjured after falling.

*** The cement did not give way at all; but was set all through the pier.

Pier No. 12.—Gault Bricks from Burham, Kent, in Cement Mortar.

6′ 0¼″ high, $18\frac{1}{4}'' \times 18\frac{1}{4}''$; sectional area 2·313 sq. ft.
Built 29th July; crushed 20th December. Age 20·5 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
12.48	10	·14	·06	—	Into bearing.
12.50½	30	9·42	4·07	—	
12.53	45	16·38	7·08	·10″	Slight internal sounds.
—	55	21·02	9·04	·15″	Ditto
12.54¼	65	25·66	11·09	·20″	
12.54½	70	27·98	12·09	—	Corner cracking off top two courses, north-east corner.
12.55	75	30·30	13·09	·25″	Spalling near bottom, south-east corner.
12.56	78	31·69	13·70	—	Splitting at top.
—	80	32·62	14·10	·28″	Spalling at top, north-east corner.
12.57	85	34·90	15·08	—	Failing four courses up from bottom.
12.58	90	37·26	16·11	—	Increasing bulge five courses up from bottom.
12·58¼	95	39·58	17·11	—	Failing badly, bulging, and splitting up.
1.0	97	40·50	17·51	—	Split up along the line of closers, and collapsed.

*** Failure from bending stress.
There were one or two pieces of stock bricks used as closers in the heart of the pier.

the work was resumed at 10 A.M. There was some trouble with air in the ram cylinder at the commencement, but this was not noticeable after the first pier had been broken.

After crushing four of the cement piers it was decided to leave the crushing of the remaining four till Thursday, 24th December. That morning, however, turned out wet, and the crushing of the remaining specimens for the first period was deferred to and completed on the 31st December.

After the piers had been crushed, Professor Unwin crushed a couple of copper cylinders, of a standard type, and noted the amount of compression at the successive pressures, so as to ascertain the real effective force of the ram after deducting friction. An account of this is added in an appendix [p. 350].

During the experiments, Mr. W. Wonnacott kindly took photographs, for the use of

Pier No. 13.—Leicester Red Bricks from Elliston, near Leicester, in Cement Mortar.

6′ 0″ high, $18\frac{3}{8}'' \times 18\frac{3}{8}''$; sectional area 2·344 sq. ft.
Built 29th July; crushed 31st December. Age 22·1 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
10.21	15	2·46	1·05	—	Brought into bearing rather suddenly.
10.33½	80	32·62	13·91	—	
10.34½	90	37·26	15·89	—	Internal crack heard.
10.35	100	41·90	17·87	$\frac{1}{16}''$	
10.36½	130	55·82	23·81	—	Going near top, four courses cracked, and also at bottom.
10.38	160	69·74	29·75	$\frac{3}{32}''$	Cracked six courses from top.
10.39	180	79·02	33·71	$\frac{1}{8}''$	Crack continuing steadily.
10.40	200	88·30	37·67	—	Crack opening.
10.41	230	102·22	43·61	$\frac{5}{32}''$	Ditto and distinct signs of failing at top.
10.41½	250	111·50	47·57	—	Ditto top six courses.
10.42½	270	120·78	51·52	—	Face still parting near top.
10.43	280	125·42	53·50	$\frac{3}{16}''$	
10.44	290	130·06	55·48	—	Failing at top, six courses down on one side, and eight courses on the other, both along line of closers.
—	300	134·70	57·46	—	Failing quietly, and shut off pressure for short time.
10.47	350	157·90	67·36	$\frac{1}{4}''$	Finally failed *by bending* suddenly, and fell immediately the joints began to open markedly.

*** Several pieces of yellow stocks were found bedded in this pier, about four courses from bottom, as closers.

Pier No. 14.—Leicester Red Bricks from Elliston, near Leicester, in Cement Mortar.

6′ 0″ high, $18\frac{3}{8}'' \times 18\frac{3}{8}''$; sectional area 2·344 sq. ft.
Built 1st August; crushed 31st December. Age 21·7 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
11.24	10	·14	·06	—	Into bearing.
11.32	30	9·42	4·00	—	
11.34	45	16·38	6·98	—	
11.38	90	37·26	15·89	—	Crack in bottom course.
11.38½	120	51·18	21·82	—	Spalling, bottom course.
11.39	130	55·82	23·81	$\frac{1}{8}''$	Two bottom courses crushing.
11.40	150	65·10	27·77	—	Crack from bottom upwards through four courses.
11.40¾	170	74·38	31·73	—	Splitting at bottom.
11.41½	190	83·66	35·68	$\frac{3}{16}''$	
11.42	210	92·94	39·65	—	Crack from bottom upwards through nine courses.
11.43	230	102·22	43·61	—	Ditto ditto ten courses.
11.44	240	106·86	45·58	—	Crack opening out, and corner coming off (photograph taken).
11.44½	250	111·50	47·57	$\frac{5}{16}''$	Corner fell away.
11.45	260	116·14	49·54	$\frac{3}{8}''$	Failed entirely. Nine courses at bottom completely crushed.

*** Many pieces of stock, blue, and gault bricks used as internal closers and filling all through; mostly fragments of stocks. The cement was set and hard.

the Institute, of the piers under stress and when crushed; Mr. T. H. Howe also took a set for Mr. Donaldson, while Mr. Garbutt made a series of sketches showing the mode of failure. A selection of these illustrations is given [pp. 335, 337, 339, 346], as affording typical examples, and Mr. Garbutt has favoured us with a short Paper, which follows this, descriptive of his observations.

This finishes the record of the first series of experiments, and while in some cases the results obtained have been unsatisfactory, it is believed that some of the information gained is quite new, and may be of great advantage to the profession. Six fresh piers to replace faulty ones have been built, and will be crushed at the end of four months, in order to give a complete and reliable estimate of the respective strengths for that period. It is, however, to the tests at the end of ten months that the committee attach the most importance, as giving the strength of brickwork when the mortar is more mature.

We owe a debt of gratitude to Professor Unwin for the interest he has taken in the general direction of our proceedings; also to Sir William Arrol and Mr. Tuit, and to Mr. Donaldson. Without the help of these gentlemen the experiments would have been impossible.

Pier No. 15.—Staffordshire Blue Bricks, from Rowley Regis, in Cement Mortar, Wire Cuts, no Frogs.

6′ 0″ high, $13\frac{1}{2}'' \times 13\frac{1}{2}''$; sectional area 1·265 sq. ft.
Built 1st August; crushed 31st December. Age 21·7 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
12.25	10	·14	·11	—	Bearing tight before starting.
12.28½	70	27·98	22·12	—	Sounds of cracking heard.
12.29½	90	37·26	29·45	—	Cracking top three courses.
12.30	110	46·54	36·79	$\frac{3}{16}''$	
12.30½	120	51·18	40·46	$\frac{1}{4}''$	Cracking top five courses.
12.31	130	55·82	44·12	$\frac{5}{16}''$	Cracking at bottom.
12.32	160	69·74	55·13		Ditto five courses.
12.32½	180	79·02	62·46	$\frac{9}{16}''$	Two cracks at bottom, six courses up.
12.33	200	88·30	69·80	$\frac{7}{16}''$	Crack, ten courses down from top.
12.33½	210	92·94	73·47	—	Crack opening top and bottom.
—	220	97·58	77·13	$\frac{1}{2}''$	
12.34	230	102·22	80·80	$\frac{9}{16}''$	Pier splitting up.
12.35	240	106·86	84·47	$\frac{5}{8}''$	Crack well opened, and pier broke entirely into a heap of rubbish. Not a whole brick could be found. Cement was still damp.

Pier No. 16.—Staffordshire Blue Bricks, from Rowley Regis, in Cement Mortar.

6′ 0″ high, $17\frac{7}{8}'' \times 17\frac{3}{4}''$; sectional area 2·203 sq. ft.
Built 25th July; crushed 31st December. Age 22·7 weeks.

Time	Pressure on gauge. Pounds per square inch	Total real pressure in tons	Pressure per square foot of pier in tons	Compression in inches	Notes
1.5	11	·60	·22	—	Into bearing.
1.8	50	18·70	8·48	—	Sounds of internal cracking.
1.8½	70	27·98	12·70	—	
1.9	90	37·26	16·91	—	Sounds of cracking.
1.9½	100	41·90	19·01	$\frac{3}{16}''$	Ditto
—	130	55·82	25·33	$\frac{1}{4}''$	
—	150	65·10	29·55	$\frac{5}{16}''$	Loud sound of cracking.
1.11	170	74·38	33·76	—	Top course cracked.
—	180	79·02	35·86	$\frac{3}{8}''$	Cracking at line of closers.
1.12	220	97·58	44·29	$\frac{1}{2}''$	Cracking at centre, mortar squeezing out.
—	240	106·86	48·50	$\frac{11}{16}''$	Cracks all over.
1.13½	280	125·42	56·93	—	Cracks opening near top.
—	300	134·70	61·14	—	Split well down, particularly at closers, and collapsed.

*** In this pier, stock brick was used generally for internal closers, giving appearance of a yellow core to pier.

Comparative Statement of Results.

No. of pier	Description of Brick	Age	Commencement of failure	Final collapse
		Weeks	Tons per sq. ft.	Tons per sq. ft.
*1.	London Stocks in mortar (with a frog)	17·7	—	—
2.	Ditto ditto ditto	18·3	4·18	10·41
3.	Gault ditto (without frogs)	18·3	5·00	21·82
4.	Ditto ditto ditto	18·8	6·16	22·03
5.	Leicester Red ditto ditto	19·1	15·20	29·93
6.	Ditto ditto ditto	18·6	16·11	31·55
7.	Staffordshire Blue ditto ditto	18·6	22·43	69·22
8.	Ditto ditto ditto	19·4	21·42	79·39
9.	London Stocks in cement (with a frog)	21·1	7·22	16·03
10.	Ditto ditto ditto	21·0	5·72	13·83
*11.	Gault ditto (without frogs)	21·0	6·98	17·98
*12.	Ditto ditto ditto	20·5	7·08	17·51
13.	Leicester Red ditto ditto	22·1	17·87	67·36
*14.	Ditto ditto ditto	21·7	21·82	49·54
*15.	Staffordshire Blue ditto ditto	21·7	29·45	84·47
*16.	Ditto ditto ditto	22·7	16·91	61·14

Duplicates of the piers marked * have been built, and will be tested for the four months' period.

The average strength of the bricks used in building the above piers, as ascertained by Professor Unwin by his tests at the Central Technical College, is as follows :—

	Crushing strength in tons per sq. ft.		Crushing strength in tons per sq. ft.
London Stocks	84·27	Leicester Red	382·1
Gault	182·2	Staffordshire Blue	701·1

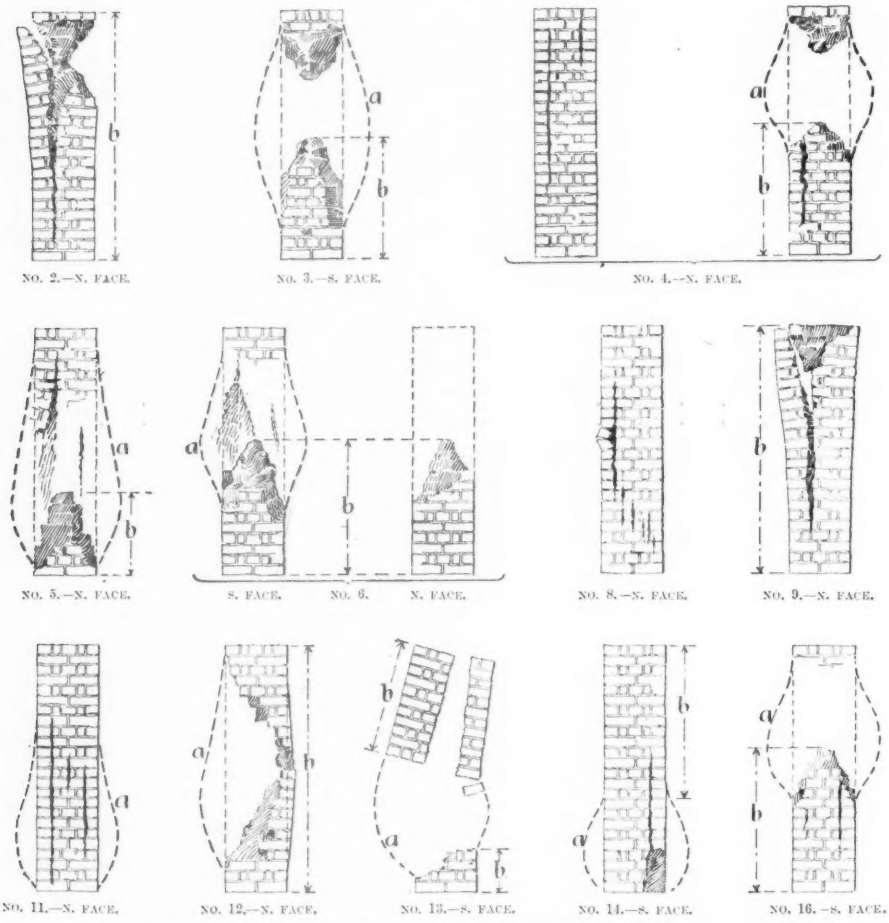
NOTES OF THE BEHAVIOUR, WHILE UNDER COMPRESSION, OF THE FIRST SERIES OF BRICKWORK PIERS. By Matt. Garbutt [*A.*].

The Science Standing Committee have honoured me with a request to prepare a brief statement descriptive of the diagrams [fig. 13] I have prepared illustrating the way in which the collapse of the piers took place, and which are based upon observations and rough sketches made by myself on the spot, and afterwards carefully compared with the photographic evidences available.

The observed effects of pressure were similar in most cases, but varied in degree with the different materials. Generally the first evidences of strain were slight internal crackling sounds, audible only on applying the ear to the brickwork. Then the mortar squeezed out of the joints and fell off—this occurring to a greater extent with the harder bricks, and being more marked where lime mortar was used than with cement. This was accompanied or followed by cracks occurring in single bricks which, from slightly irregular bedding, or other cause, were unevenly stressed, and by the spalling off of small corners or pieces of the face for similar reasons. By this time the joints were generally noticeably compressed, and serious cracks, indicating final lines of rupture, appeared. The piers at this point generally bulged outwards, slowly at first, and then, the resistance of the brickwork ceasing, the falling of the pressure gauge gave warning that actual collapse was imminent. In the case of the harder bricks set in cement the final failure was much more sudden than in the others, so much so that some agility was necessary on the part of the man who, to measure its compression, stood close to the pier. It will be desirable, before carrying out the proposed 9-month tests, to devise an instrument for measuring, without undue risk to the observer, the actual shortening of the piers during testing.

From the beginning of the tests all through the series it was evident that the vertical line of joints formed by the closers was a plane of weakness, and it was generally at this line that the serious cracks first showed themselves. The majority of the piers broke by crushing in the normal way, or in a manner closely approximating thereto. The pier No. 3, of Gault Bricks in mortar, presented a good typical example. It bulged evenly and on all sides at once, nearly every brick in the body of the pier was broken, and the two pyramids at top and bottom remaining after the crushing of the mass were regularly defined and approximately concentric with the axis of the pier.

There were, however, one or two departures from the type of fracture generally to be expected in short piers. Of these exceptional cases No. 12 was the most remarkable. This pier was of Gault Bricks in cement, and it appeared that, from some cause not readily to be detected, the stresses were not evenly distributed over the whole area of the pier. The first visible signs of injury were spallings



a . . . a, Approximate outline during final collapse. *b . . . b*, Portions which remained in shape after collapse of pier.
Approximate scale of four feet to one inch.

FIG. 13.—DIAGRAMS SHOWING WAYS IN WHICH PIERS FAILED.

Reproduced from drawings by Mr. Matt. Garbutt [*sic*].

of the bricks on one side of the pier; then splitting occurred at the lines of closers on the adjacent sides, and finally the side which first showed injury crushed and the pier failed by bending. The cement was found to be quite disintegrated, and as the corresponding pier, No. 11, which was subjected to almost exactly the same pressure, showed its cement to be perfectly hard, set, and uninjured by crushing, one is led to conjecture that the cement used in No. 12 had been left mixed overnight and beaten up again

in the morning, or that the bricks had not been sufficiently wetted, and had withdrawn the moisture from the cement.

Pier No. 2, of London Stocks in Mortar, split down at the line of closers, only the extreme bottom course being unbroken, and crushed at the top, two pyramids being formed with their apices in contact about five courses from the top of the pier. The mortar was not fully set.

Pier No. 4, of Gault Bricks in Mortar, gave way somewhat similarly to No. 2, by crushing near the top.

Pier No. 5, of Leicestershire Red Bricks in Mortar, failed from the bottom, giving way very steadily, and bulging evenly all round.

Pier No. 6 was of the same materials as No. 5, but failed in a somewhat different manner, displaying a diagonal crack on one side indicative of a tendency to fail by sliding; but this did not extend right through the pier, all the serious splits upon the other faces being vertical at the lines of the closers, and the failure was chiefly due to crushing. A photograph was secured showing the diagonal crack, and is of interest as illustrating the only example of the kind which was observed in the sixteen piers tested.

Pier No. 7, of Staffordshire Blue Bricks in Mortar.—The behaviour of this pier under compression was in several ways different from that of any of the other piers built in mortar, because of the disproportion between the strength of the mortar and that of the bricks used. Until the pressure reached 16 tons per square foot there was no sign of any injury to the pier, but at this point the mortar began to show signs of distress and internal cracking sounds became audible. No visible cracks occurred, however, until 28 tons per square foot had been applied, at which time the pier had been compressed half an inch. When pressure had risen to 45 tons the joints of the pier crushed suddenly and considerably, and from this time until complete failure occurred mortar was falling freely from the joints. The final crushing was at the centre of the pier, and occurred just before 70 tons per square foot was reached.

Pier No. 8.—This was a Staffordshire Blue Brick pier in mortar, like the last; and here again the relative weakness of the mortar became evident, the pier being shortened one inch by crushing of its joints under a pressure of 59 tons per square foot. The weakness caused by the closers was marked here by the bursting off of strips $4\frac{1}{2}$ inches square and about 2 feet long from the angles at the centre of the height of the pier: this was quickly succeeded by the final collapse.

Pier No. 9, of Stock Bricks in Cement.—The way in which this pier failed was very curiously like the way in which No. 2—of the same bricks, but set in mortar—failed. It split from top to bottom near the centre, but, instead of having two opposing pyramids, it had one which appeared to act as a wedge tending to assist the splitting process.

Pier No. 11, of Gault Bricks in Cement, failed by crushing near the bottom, the worst cracks first appearing at the line of closers. The cement, as previously mentioned, was set and hard, and did not give way appreciably: this to a great extent prevented the crushing of the bricks, which were much less shattered than in the mortar-built piers.

Pier No. 13, of Leicestershire Red Bricks in Cement, displayed a combination of crushing and bending. Under a pressure of 26 tons per square foot, it had been compressed rather more than $\frac{1}{16}$ inch, and then it began to crack near the top, the crack (which was at the line of closers) steadily continuing and opening until the pressure reached 67 tons per square foot, when the pier suddenly bent and fell, a considerable mass of the upper portion remaining intact after its fall.

Pier No. 14, of Leicestershire Red Bricks in Cement.—The chief noticeable feature about this pier was that although it seemed an almost exact duplicate (as was intended) of No. 13, and the cement was thoroughly and properly set, yet it proved to have only three-fourths of the strength of No. 13. This pier was badly built, the core being filled with fragments of London Stocks. Its failure, which occurred near the bottom, was normal.

Pier No. 15, of Staffordshire Blue Bricks in Cement.—This pier was only $13\frac{1}{2}$ inches square, being built of this size because it had been suggested that the machine employed might be unable to crush the 18-inch square pier of blue bricks in cement. It proved fully 25 per cent. stronger in proportion to its area than the 18-inch pier, the difference being probably due to the better bond and absence of

closers. It failed entirely by crushing, and was so completely destroyed that I could find only one whole brick remaining. The cement was still damp.

THE FIRST SERIES OF BRICKWORK TESTS: REPORTS AND NOTES.

By Professor Unwin [*M.A.*], B.Sc., F.R.S.

I.—REPORT ON CRUSHING TESTS OF SAMPLES OF BRICKS USED.

Date of test	Description	Dimensions in inches	Area crushed in square feet	Loads in tons		Stresses in tons per square foot		Mean crushing strength in tons per square foot
				Cracking	Crushing	Cracking	Crushing	
1895								
Oct. 3	London Stocks . . .	9·05 × 4·25 × 2·65	·267	22·38	25·265	83·8	94·6	84·27
Oct. 3	Ditto . . .	9·10 × 4·10 × 2·7	·259	—	23·10	—	89·15	
Oct. 23	Ditto . . .	8·8 × 4·05 × 2·6	·247	21·3	22·91	86·06	92·56	
Oct. 24	Ditto . . .	9·1 × 4·3 × 2·75	·272	16·0	16·51	58·88	60·76	
Oct. 3	Gault	8·7 × 4·2 × 2·7	·254	—	45·55	—	179·5	182·2
Oct. 3	Ditto	8·8 × 4·15 × 2·7	·254	22·5	50·12	88·7	197·6	
Oct. 23	Ditto	8·8 × 4·2 × 2·8	·257	29·0	42·83	113·0	166·9	
Oct. 23	Ditto	8·9 × 4·3 × 2·8	·266	28·0	49·155	105·3	184·9	
Oct. 3	Leicester Red (half brick) .	4·3 × 4·07 × 2·7	·121	43·655	71·855	359·3	591·4	382·1
Oct. 3	Ditto .	4·3 × 4·3 × 2·8	·128	—	39·99	—	311·4	
Oct. 23	Ditto .	4·6 × 4·35 × 2·75	·139	28·6	43·41	201·5	312·3	
Oct. 23	Ditto .	4·5 × 4·25 × 2·75	·133	25·0	43·30	188·3	326·0	
Oct. 24	Ditto .	4·4 × 4·3 × 2·8	·131	32·0	48·515	243·5	369·2	
Oct. 3	Blue Stafford (half brick) .	4·4 × 4·25 × 2·7	·130	44·50	100·0*	342·5	770*	701·1
Oct. 10	Ditto .	3·0 × 4·25 × 2·7	·088	—	50·0	—	564·8	
Oct. 10	Ditto .	4·3 × 4·1 × 2·75	·122	62·27	70·375	509·5	575·8	
Oct. 23	Ditto .	4·15 × 4·3 × 2·75	·124	50	100·0*	403·5	807*	
Oct. 23	Ditto .	4·3 × 4·25 × 2·75	·127	80	100·0	631	788	

* These specimens were *not* crushed with 100·0 tons.

II.—REPORT ON CRUSHING TESTS OF SAMPLES OF BRICKS AND HALF-BRICKS USED.

Some of the bricks used in building the piers were so strong that they could not be crushed as whole bricks in the 100-ton testing machine. They were therefore cut in half and tested as half-bricks.

It is well known that the pressure at which solid prisms crush, reckoned per unit of area of the surface supporting the pressure, varies with the form and proportions of the prism. In particular, the crushing pressure diminishes as the ratio of the height to the horizontal dimensions increases. It is not likely, therefore, that a half-brick will carry exactly half the load that a whole brick will carry.

It seemed desirable to obtain a measure of the relative resistance of whole and half-bricks. Three qualities of brick were selected and prepared for testing, both as whole and half-bricks, with the usual plaster facing to secure parallel plane surfaces to support the crushing pressure.

The following table gives the results of the tests:—

Description	Dimensions in inches	Area crushed in square feet	Loads in tons		Stresses in tons per square foot		Mean crushing stress. Tons per square foot
			Cracking	Crushing	Cracking	Crushing	
London Stock . . .	9·1 × 4·3 × 2·8	·272	—	25·26	—	92·85	92·85
Ditto (half-brick) .	4·7 × 4·4 × 2·8	·144	—	6·845	—	47·54	46·94
Ditto (half-brick) .	4·6 × 4·3 × 2·8	·137	—	6·350	—	46·35	
Red Rubber	9·9 × 4·9 × 3·4	·337	18·135	28·35	53·80	84·11	84·11
Ditto (half-brick) .	4·9 × 4·8 × 3·3	·163	—	9·695	—	59·48	58·71
Ditto (half-brick) .	5·0 × 4·8 × 3·3	·167	—	9·675	—	57·94	
Gault	8·9 × 4·1 × 2·8	·253	45·465	48·64	179·7	192·2	192·2
Ditto (half-brick) .	4·4 × 4·2 × 2·8	·128	17·88	22·575	139·7	176·4	160·7
Ditto (half-brick) .	4·7 × 4·3 × 2·8	·140	16·98	20·29	121·3	145·0	

It appears that the half-bricks are very markedly weaker than the whole bricks. The following statement gives the results on half-bricks expressed as a percentage of the strength of whole bricks:—

Description	Strength of whole bricks per square foot	Strength of half-bricks per square foot
London Stocks	100	50
Red Rubbers .	100	70
Gault . .	100	83

The London Stocks are of very rough composition and cannot be divided very neatly. They are also very irregular in strength. Excluding them, it would appear that bricks tested as half-bricks may be expected to crush with about 25 per cent. less pressure per square foot than the same bricks tested as whole bricks.

III.—REPORT ON TESTS OF LIME AND CEMENT USED IN THE CONSTRUCTION OF THE EXPERIMENTAL PIERS AT THE WEST INDIA DOCKS.

By arrangement, parcels of lime and cement, as used at the West India Docks, and also a small quantity of the sand used there, were forwarded to the Central Technical College. The quantity of sand was not sufficient for making more than a few briquettes, and therefore it was decided to use for most of the briquettes the standard washed and sifted sand which has been generally adopted for cement tests, and which is obtained from Leighton Buzzard. A few briquettes were made with the sand used in building the piers, and this is referred to below as special sand. A number of compression briquettes, cubes of 3 inches length of side, were carefully made, and when removed from the moulds were placed under water to harden. The results of the first tests of these are given in the following tables. A reserve of briquettes has been retained for testing at later dates :—

Lime Briquettes.—Composed of two of sand to one of lime by volume.

No. of specimen	Description	Date of making 1895	Date of testing 1895	Age. Weeks	Dimensions in inches: Crushed section	Dimensions in inches: Height	Area in square feet	Breaking load in tons	Crushing stress. Tons per square foot
L. 1	Standard sand	October 4	October 31	4	3·00 × 3·00	2·99	0·0625	0·344	5·50
L. 2	Ditto	October 4	October 31 1896	4	3·00 × 3·00	3·02	0·0625	0·416	6·66
L. 6	Ditto	October 7	January 7	13·1	3·00 × 3·05	3·00	0·0635	0·515	8·11
L. 7	Ditto	October 28	January 15	11·3	3·00 × 3·00	3·01	0·0625	0·585	9·36
L. 3	Ditto	October 4	March 20	24	3·00 × 3·00	2·99	0·0625	0·946	15·14
L. 4	Ditto	October 7	March 20	23·6	3·00 × 3·00	2·97	0·0625	0·961	15·38
L. 5	Ditto	October 7	March 20	23·6	3·00 × 3·00	3·01	0·0625	1·041	16·65

Strength at 4 weeks, 6·08 tons per sq. ft.
Ditto 12 weeks, 8·73 ditto.
Ditto 24 weeks, 15·72 ditto.

Cement Briquettes.—Composed of four of sand to one of cement by volume.

No. of specimen	Description	Date of making 1895	Date of testing 1895	Age. Weeks	Dimensions in inches: Crushed section	Dimensions in inches: Height	Area in square feet	Breaking load in tons	Crushing stress. Tons per square foot
1	Standard sand	October 2	October 31	4	2·99 × 3·02	3·06	0·0627	2·196	35·03
3	Ditto	October 2	October 31 1896	4	3·00 × 3·00	3·03	0·0625	1·741	27·86
7	Ditto	October 3	January 7	13·7	3·00 × 3·00	3·02	0·0625	2·670	42·71
11	Ditto	October 3	January 7	13·7	3·00 × 3·03	3·00	0·0631	3·428	54·32
4	Ditto	October 2	March 19	24	3·00 × 3·02	3·00	0·0629	3·085	49·04
5	Ditto	October 2	March 19	24	3·00 × 3·01	3·00	0·0627	3·790	60·44
8	Ditto	October 3	March 19	24	3·02 × 3·00	3·00	0·0629	3·710	58·97
2	Special sand	October 2	March 19	24	3·01 × 3·02	2·99	0·0631	2·152	34·11
6	Ditto	October 2	March 19	24	2·98 × 3·00	3·00	0·0621	1·484	23·90

Mean strength at 4 weeks, 31·45 tons per sq. ft.
Ditto 13·7 weeks, 48·52 ditto.
Ditto 24 weeks, 56·15 ditto.

Mean strength of briquettes made with same sand as that used in building the piers = 29·00 tons per sq. ft. at 24 weeks.

IV.—DETERMINATION OF THE LOADS CORRESPONDING TO THE GAUGE PRESSURES FOR THE LARGE HYDRAULIC PRESS AT THE WEST INDIA DOCK.

The hydraulic press has a ram 3 ft. 1⅞ in. in diameter, or of 1,130 sq. in. area. Hence, if there

were no cup leather friction or other force affecting the action of the press except the water pressure, the load due to any gauge pressure would be as follows:—

Let a = ram area in sq. in. = 1,130.
p = gauge pressure in lb. per sq. in.

Then total pressure of ram or load on brick column

$$= \frac{pa}{2240} = 0{\cdot}5044\ p \text{ ton.}$$

The cup leather friction is, however, considerable, the weight of the ram itself balances part of the water pressure, and there are possible inaccuracies of the pressure gauge.

To determine the true effective crushing load of the ram due to any gauge pressure, the following method was adopted. Some cylinders of copper of very uniform quality were prepared. Two of these were tested in the testing machine at the Central Technical College, and the compressions corresponding to different loads accurately determined. After the trials of the brick columns on 31st December, two similar copper cylinders were crushed in the hydraulic press, and the compressions corresponding to different gauge pressures were determined. From these data it was possible to determine very accurately the true effective crushing pressure exerted by the ram at different gauge pressures. The results obtained proved very consistent and satisfactory, notwithstanding the fact that in the case of so large a press it is unlikely that the friction is quite exactly constant.

Two sizes of copper cylinders were used, the smaller giving better results for the lower and the larger for the higher pressures.

Cylinder 1683—Diameter 0·938 inch; length 1·879 inch.
„ 1688— „ 1·097 „ ; „ 2·132 „

Observations on Copper Cylinders (31st December 1895): Hydraulic Press at West India Dock.

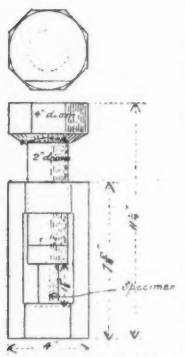


FIG. 14.—CRUSHER GAUGE.

Pressure by gauge. Pounds per square inch	Cylinder 1688		Cylinder 1683	
	Micrometer reading in inches	Compression in inches	Micrometer reading in inches	Compression in inches
10	2·582	—	2·291	—
15	—	—	2·288	·003
20	2·581	·001	2·282	·009
25	2·580	·002	—	—
30	2·577	·005	2·274	·017*
40	2·570	·012	2·061	·230
50	2·456	·126	1·796	·495
60	2·209	·373	1·594	·697
70	2·005	·577	—	—
80	1·816	·766	1·293	·998
90	1·670	·912	—	—
100	1·558	1·024	—	—
110	1·468	1·114	—	—
130	1·355	1·227*	—	—

A comparison of the results showed that the true load corresponding to any gauge pressure would be given very approximately by the following formula:—

$$\text{Effective load} = \text{L} = 0{\cdot}464\ p - 4{\cdot}5 \text{ tons} \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

It may be noted that in the two series of observations different parts of the ram were used, and if these were not exactly of the same roughness some small difference in the friction would arise.

The following table shows the comparison of the effective load. The compressions and loads in the tests at the Central Technical College were plotted in a curve. Using this curve, the effective loads for the compressions at different gauge pressures at the West India Dock were obtained and are given in the following table. Also the loads calculated by formula (a) and the calculated loads neglecting

* The ram moved not quite regularly, but in small jerks. Hence, absolutely consistent results could not be expected. I think these two results the least regular and satisfactory of the series, and I have given less weight to them in calculating formula (a).—W. C. U.

friction. The difference of the load calculated from the ram area and pressure and that calculated by formula (*a*) is the friction and unbalanced weight of the press :—

Comparison of Gauge Pressures, calculated Loads neglecting Friction, and true effective Loads of Ram, at West India Dock.

Observed gauge pressure. Pounds per square inch	Calculated load on ram neglecting friction, &c., in tons	Effective loads from compression of cylinders		Mean effective load of ram in tons from plotted curve	Load calculated by formula (*a*) in tons	Friction of ram in tons
		Cylinder 1683 in tons	Cylinder 1688 in tons			
10	5·04	—	—	—	0·14	4·90
15	7·57	2·50	—	2·50	2·46	5·11
20	10·09	4·70	—	4·70	4·78	5·31
30	15·13	7·60	—	7·60	9·42	5·71
40	20·18	14·00	—	14·00	14·06	6·12
50	25·22	19·24	19·10	19·17	18·70	6·52
60	30·26	24·38	23·48	23·93	23·34	6·92
70	35·31	—	28·15	28·15	27·98	7·33
80	40·35	33·80	33·09	33·44	32·62	7·73
90	45·40	—	37·40	37·40	37·26	8·14
100	50·44	—	41·73	41·73	41·90	8·54
110	55·48	—	45·82	45·82	46·54	8·94
130	65·58	—	51·80	51·80	55·82	9·76

V.—AMERICAN TESTS OF BRICK PIERS IN LIME AND CEMENT MORTAR.

The only series of tests hitherto made which are similar to those undertaken by the Committee is one made in the United States by a Committee of the American Society of Civil Engineers in 1887–88. The following is a short abstract of the results of these tests reduced to the same units and put in a form in which they can be easily compared with the present experiments.

The bricks used were of three kinds.

	Crushing strength. Tons per sq. ft.
Hard burned face bricks	890
Ditto ditto common bricks	1170
Bay State medium bricks	730

Thirty-three brick piers were built of these bricks of various forms and sizes. The bricks were laid on the bed with joints broken in every course, except in two cases. Their ages when tested varied from fourteen to twenty-four months. The tests were made on the 500-ton testing-machine at Watertown. Piers built with Portland cement gave the highest resistance, showing that the quality of the mortar affects the strength of the pier. The piers in lime mortar compressed most, and the yielding appeared to be chiefly in the joints. The compressions were measured and are given, but it has not seemed necessary to abstract these. The following tables give the whole of the results on the crushing of piers :—

Brick Piers in Cement Mortar.

Kind of brick	Mortar	Form of pier	Nominal size in square inches	Area of section in square feet	Height in inches	No. of courses	Thickness of joints	Age in months	Crushing pressure in tons per square foot
Common	1 Portland, 2 sand . .	Solid	16	1·56	121	49	$\frac{1}{4}$	24	121
Ditto .	Ditto . .	Ditto	12	0·95	120	58	$\frac{1}{4}$	24	128
Face .	Ditto . .	Ditto	12	0·91	119	51	$\frac{3}{16}$	$23\frac{1}{2}$	144
Ditto .	Ditto . .	Ditto	8	0·40	80	35	$\frac{1}{4}$	23	144
Ditto .	Ditto . .	Ditto	12	0·92	$23\frac{1}{2}$	10	$\frac{3}{5}$	$18\frac{1}{2}$	234
Common	Ditto . .	Ditto	16	1·77	$23\frac{1}{2}$	13	$\frac{1}{2}$	$18\frac{1}{2}$	Not given
Bay State	1 Rosendale, 2 lime, 6 sand	Ditto	12	1·00	$73\frac{5}{8}$	30	$\frac{3}{11}$	$20\frac{1}{2}$	105
Ditto .	1 Rosendale, 2 sand . .	Ditto	12	1·00	$72\frac{1}{4}$	30	$\frac{3}{16}$	20	126
Ditto .	1 Portland, 2 sand . .	Ditto	12	1·00	$72\frac{5}{8}$	29	$\frac{3}{16}$	20	115
Ditto .	1 Portland, 2 lime, 6 sand .	Ditto	12	1·00	$73\frac{3}{8}$	30	$\frac{3}{16}$	$20\frac{1}{2}$	91
Ditto .	Neat Portland . . .	Ditto	12	1·00	72	30	$\frac{1}{16}$	$19\frac{1}{2}$	152

Brick Piers in Lime Mortar (1 Lime and 3 Sand).

Kind of brick	Form of pier	Nominal size in square inches	Area of section in square feet	Height in inches	No of courses	Thickness of joints	Age in months	Crushing pressure in tons per square foot
Face	Solid	8	0·395	—	7	—	15	163
Common	Ditto	8	0·420	—	7	—	15	156
Face	Ditto	12	0·92	—	10	—	18½	125
Ditto	Hollow (space $4\frac{1}{2} \times 4\frac{1}{4}$)	12	0·79	—	10	—	18½	128
Common	Solid	12	0·96	—	10	—	18½	138
Ditto	Hollow (space $4\frac{1}{2} \times 4\frac{1}{2}$)	12	0·83	—	10	—	18½	131
Bay State	Solid	12	1·01	—	10	—	18½	88
Ditto	Ditto	12	1·00	$72\frac{1}{2}$	30	$\frac{3}{16}$	19½	73
Ditto	Ditto	12	1·00	$72\frac{1}{4}$	30	$\frac{3}{16}$	20	85
Ditto	Ditto	12	1·08	73	19 (on edge)	$\frac{1}{2}$	20	78
Face	Ditto	8	0·40	80	35	$\frac{1}{8}$	23	120
Bay State	Ditto	12	1·00	$94\frac{1}{4}$	39	$\frac{3}{16}$	23½	75
Ditto	Ditto	12	1·00	$119\frac{3}{4}$	49	$\frac{3}{16}$	23½	59
Common	Hollow (space $4\frac{3}{4} \times 4\frac{3}{4}$)	12	0·80	$120\frac{3}{4}$	50	$\frac{1}{4}$	24	101
Ditto	Solid	12	0·96	$117\frac{1}{2}$	49	$\frac{1}{4}$	24	76
Face	Ditto	12	0·92	$119\frac{1}{4}$	52	$\frac{1}{8}$ to $\frac{3}{16}$	24	97
Ditto	Hollow (space $4\frac{1}{10} \times 4\frac{1}{10}$)	12	0·80	$119\frac{1}{4}$	52	$\frac{1}{8}$	24	115
Bay State	Solid	12×16	1·33	$120\frac{1}{2}$	49	$\frac{1}{4}$	24	50
Ditto	Ditto	8×12	0·66	$120\frac{3}{4}$	49	$\frac{1}{4}$	24	60

ANALYSES OF SAMPLES OF MORTAR AND CEMENT MORTAR.

By W. J. Dibdin, F.I.C., F.C.S.

At the request of Mr. Blashill, an analysis of samples of mortar taken from the débris of the piers experimented upon was made by Mr. Dibdin, Chemist to the London County Council, with the following results:—

—	Pier No. 4. Gault Brick. 17th Dec. 1895	Pier No. 5. Leicester Wire. 17th Dec. 1895	Pier No. 7. Blue Stafford. 17th Dec. 1895	Pier No. 9. Stocks in cement crushed at 44 tons. 20th Dec. 1895	Pier No. 11. Gault Brick in cement crushed at 50½ tons. 20th Dec. 1895	Pier No. 13. Leicester Wire cut red, 175 tons on 18 piers. 31st Dec. 1895	Pier No. 15. Blue Stafford Brick, 120 tons on 14 piers. 31st Dec. 1895	Pier No. 16. Stafford Blue Brick, 150 tons on 18 piers. 31st Dec. 1895
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	7·69	6·92	9·88	4·95	3·94	5·72	6·16	8·26
Lime (CaO)	13·79	12·18	10·66	11·80	10·87	11·97	9·20	11·24
„ carbonate	1·02	1·36	1·06	2·86	2·86	1·04	1·87	1·45
„ sulphate	0·17	0·51	0·17	0·20	0·30	0·99	0·84	0·71
Iron and alumina	2·05	2·80	2·65	4·35	3·75	4·00	4·95	4·00
Soluble silica	0·90	1·00	0·58	3·25	2·50	3·25	2·00	2·25
Earthy matter	0·14	0·74	0·81	0·61	0·64	0·96	0·85	0·70
Loss on ignition	1·74	1·07	1·69	2·09	2·19	2·42	2·50	2·02
Water of hydration, &c.	2·85	2·11	2·03	2·55	2·18	2·00	1·10	1·42
Sand and grit	69·65	71·31	70·47	67·34	70·77	67·65	70·53	67·95
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

DESCRIPTION OF THE HYDRAULIC TESTING-MACHINE.

By J. E. Tuit, M.Inst.C.E.

The machine used in making the experiments was designed especially for the purpose, and consisted of steel box girders, connected together by angle bars, as shown in the diagram, fig. 15. An hydraulic press, having a ram 3 feet $1\frac{7}{8}$ inch diameter, rested upon the lower of the box girders, sufficient head-room being allowed above it to permit the piers being brought into position directly over the centre of the press.

The upper part of the ram being provided with a cup and ball bearing insured that the line of pressure always coincided with the longitudinal axis of the pier which was being tested.

The hydraulic pressure was obtained from the Dock Company's mains, but, as this did not exceed 750 lb. per square inch, additional means were provided for increasing it by means of small hand-pumps placed near the press.

The actual water-pressure at any moment was shown by means of two hydraulic gauges — one registering pressures up to 250 lb. per square inch, and the other to 2,500 lb. per square inch. Correction was made for the friction of the ram as described above by Professor Unwin.

The whole of the steelwork of the machine was so proportioned that a pressure of 500 tons could be safely exerted on any specimen, this corresponding to a water pressure of about 1,000 lb. per square inch, taking the effective area of the ram as 1,130 square inches.

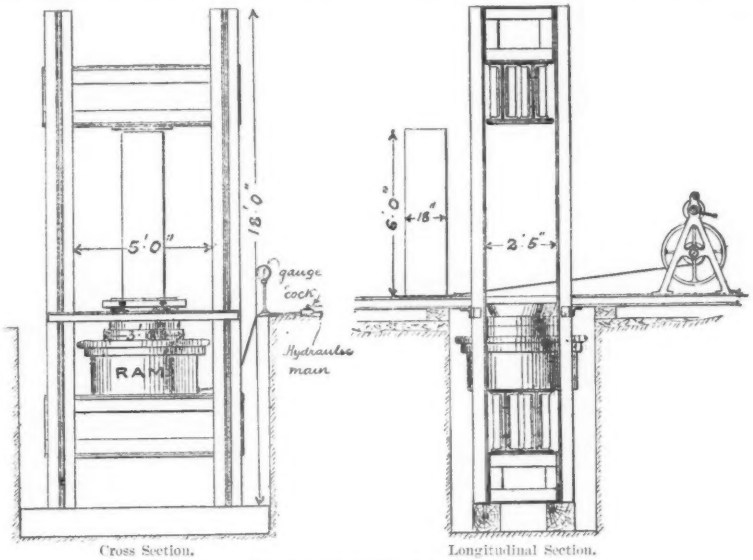


FIG. 15.—THE TESTING-MACHINE.

Great care was exercised in allowing the pressure to enter the press very gradually, and, owing to the small inlet provided and the large area of the cylinder, the vertical motion of the ram was very slow.

DISCUSSION OF THE FOREGOING PAPERS.

Mr. ALEX. GRAHAM, F.S.A., *Vice-President*, in the Chair.

PROFESSOR UNWIN [*H.A.*], F.R.S. — Mr. Chairman, before touching on some tests left to me to explain, I should like to make a few introductory remarks. If you exclude soft bricks, if you take bricks such as would be used in a case where strength is necessary, single bricks will carry from 200 to 1,000 tons or more per square foot. Now, according to the best of my knowledge of the limits of working stress which have been allowed in brickwork, in cases where brickwork is required to carry a heavy load, the limits which are prescribed are something like this: For bricks in lime mortar, not more than from two to four tons per square foot; for bricks in cement mortar, not more than from four to seven tons per square foot; and for specially selected hard bricks in cement mortar, where very great strength is required, from seven to eight tons per square foot. Obviously, without any further knowledge, you can see that, allowing even for loss of strength at the joints, the ratio of working stress to the probable breaking or crushing strength of the brickwork is a very small one—much smaller than in most structures with which the engineer has to do. An iron or steel bridge is loaded up to about one-fourth, or at any rate one-fifth, of its probable breaking weight. A boiler which is subjected to corrosion and other causes of deterioration is loaded to one-sixth or one-seventh of the pressure which would burst it, but the factor between the working load and the breaking strain in cases of brickwork must be something much more like 20 to 1—a very large factor indeed. No doubt the reason of that in part is, that a brickwork structure is a heterogeneous structure, and not a homogeneous structure, and we have to allow something for planes of weakness at the joints; but I imagine that the large factor between the working stress and the breaking stress is to a great extent an expression of our ignorance of the real strength of the brickwork; and it is to supply in some measure data as to the real strength of brickwork that this series of experiments has been undertaken; and, unless I mistake, when they are complete they will afford the largest single mass of information which has ever been put forward as to the real strength of brickwork. Now, I have had in the course of these experiments to talk with

various people about them, and there are one or two points I wish to bring to your attention. I have been told that what we want is a ratio. Well, if that is intended to mean that you can take a little briquette of cement and test it, and take a single brick and test it, and that with these data you can go to a table and find a ratio which will give you the strength of any single pier, I am afraid we are still a century or two off the amount of knowledge required for that purpose. And in fact I do not quite like the expression that we are seeking a ratio. What an architect or an engineer wants to know, I suppose, is the absolute measure of the strength of the things he is building; he wants to know what is the actual load he dare put upon them. Now at all events it is quite clear that with bricks of different strengths to begin with, we shall get piers of different resistance when built. I do not think the ratio between the strength of a brick and the strength of a pier will be at all a simple one, but there will be some relation between the strength of the bricks and the strength of the piers, and therefore one of the inquiries which were carried out has been to make a series of tests of the bricks actually employed. A table of the strength of the bricks has been given, and some members of the Science Committee were good enough to come to the Central Technical College and to see some of the bricks tested, and how the work was done. You will see that the London stocks carried only about 84 tons to the square foot before they crushed, and the good Staffordshires went up to at least as high as 700 tons to the square foot; so we have bricks of very wide variations of strength. I had only a testing-machine that would go up to 100 tons, and in making those tests I found that in the case of the strongest bricks I could only test them as half-bricks, not as whole bricks. Therefore it occurred to me, Is there any difference between the strength of a half-brick per square foot and the strength of a whole brick per square foot? And I made a few tests on the strength of half-bricks and the strength of whole bricks of the same kind, and it comes out that generally the half-bricks are not quite so strong on the square foot as the whole bricks—a result which on theoretical grounds one might have expected. But I want to put in a special caution. In the case of London stock bricks the tests indicate that the half-bricks only carried half as much per square foot as the whole bricks. I am pretty sure that in that case we got a strong brick to test as a whole brick and a much weaker brick to test in half-bricks, and that the result exaggerates the difference considerably. Since then I have looked up some older results of mine on half-bricks and whole bricks, and I do not find, even in the case of London stock bricks, so large a difference as that. No doubt, on the average, the half-brick does not give quite so great a strength per square foot as the whole brick. It was desirable also that we should know something about the mortar and the cement that we used; and some of the lime and cement and sand was sent down to me for testing. As these are cases where the cement and mortar are used in compression I elected to test the lime and cement in compression. The ordinary way of testing—cement at any rate (lime mortar is very seldom tested)—is to make a small briquette of neat cement, and test it at the end of a week. That is a very valuable test, if you want to know whether the cement-maker is keeping up a certain standard quality of cement; it is quite useless in considering the strength of piers such as these, where the cement is mixed with sand and used in compression. I elected to make tests in compression and to make tests of mortar briquettes. The contractor did not send me very much of the sand of which the piers were made—only enough to make a briquette or two. I am not sure that was a misfortune, because I think on the whole it is better to use exceedingly good and pure sand, and I made most of the briquettes with what is the nearest approach to standard sand in this country—the sand selected many years ago by Mr. Grant, of the Metropolitan Board, and used since by the late Mr. Faija, myself, and others as a standard. It is an exceedingly pure and clean sand, obtained from Leighton Buzzard. The briquettes made with standard sand were nearly twice as strong as those made with the sand used in building the piers. This is not at all a surprising difference, because the sand used on the works had more or less earthy matter with it. So much for the materials. I believe I am somewhat responsible for the fact that an hydraulic press was used in these tests. When I was asked to join the Committee these tests were under consideration, and my old friend Mr. Faija had suggested that tests of this kind could be made by rigging up some kind of temporary lever for crushing the piers. I did not see my way, without a very large expense indeed, to rigging up any kind of lever which would satisfactorily test piers requiring loads of 100 tons, and probably 200 or 300 tons, and I suggested the use of an hydraulic press. The press we have been using is not an unprecedentedly large one—there have been larger—but it is an exceptionally large press. I went to Sir Benjamin Baker, and said, "We want "a very big press, and want to borrow one for a "long time." And I asked him whether he knew where we could get one, and he said if the Institute went to Sir William Arrol he would probably lend one; and Sir William was good enough also, in addition, to construct the steel work required to convert the press into a testing-machine. Now, presuming a press to be used, I had to consider one point. An hydraulic press used as a testing-machine has got a very bad name, and not undeservedly, because what the pressure-gauge on the hydraulic press directly gives you is only the pressure in the ram cylinder, and it does not give

the load that the press exerts. There is a difference between the two, due to the very large friction of the ram. That friction is as low as 4 per cent. in some cases, and in other cases it rises up to 25 per cent. of the load that the press exerts; and although 25 per cent. error would not be so large an amount that it would entirely destroy the value of these experiments, still it was very desirable indeed that we should know more accurately than within 25 per cent. what the real load exerted by the press was; and at any rate to avoid criticism of the results, it was desirable that we should have some independent check on the load that the press exerted. It occurred to me then that we might get very accurately indeed the actual load that the press exerted by a method analogous to that used in testing the pressure of gunpowder in a gun. By preparing some copper cylinders and crushing one in a very accurate testing-machine, and observing what its compression was for any particular load, and then by crushing another of exactly the same quality in the actual press, and observing what its compression was, we could determine exactly what the force of the press was corresponding to any particular pressure on the pressure-gauge. I have here some cylinders that we have crushed, and the results that we worked out of the compressions with copper cylinders come out even more uniformly than one could have hoped. I believe we have determined the real loads exerted on those piers with an accuracy of something under 1 per cent. Then let me say this: I have heard some people say that, after all, the experiments are not much use, because we know all about brickwork. Now, it is my business to know something about testing, and I think I know probably, at any rate, all the published results in the testing of brickwork. They are astonishingly few. The earliest that I know of are some made during the building of the Menai and Conway Bridges. The engineers built some 10-inch cubes of brickwork in cement, but they do not say what cement. I suppose it was Roman cement. And they also forgot to give the age at which they were tested; but I suppose they would be two or three months old, and they carried 33½ tons per square foot before crushing. When you put those aside, there are hardly any others down to a very recent date indeed. Dr. Böhme at Berlin, who tests building materials for the German Government, made some very valuable tests on 10 inch cubes of brickwork made with cement and lime mortar; but there are no tests in actual structures of brickwork at all comparable to those which the Committee have undertaken, except a series carried out in America by the American Institution of Civil Engineers. The tests were made with the magnificent testing-machine at Watertown Arsenal. I thought it would be interesting to members to have those tests at hand, to compare with the tests that the Science Committee of the Institute have been making, and I have prepared an abstract of those American experiments, reduced to the same units, and tabulated so as to be easily comparable with the results obtained by your Committee. You will find that those tests give larger crushing pressures than we have at present obtained on any of the piers. That is due to two causes. In the first place, the Americans used very strong bricks, stronger indeed than any we have been using; and in the second place, their piers were tested, a few of them at fourteen months old, most of them at twenty-four months old, and for that reason alone they would be stronger piers than those we have been testing. I think I have only one word more that I should like to say at present, and that is as to the way in which these piers give way. Although we talk of crushing these things, so far as I know in brittle materials of this kind there is no such thing as crushing. These piers have not given way by crushing; they have given way by shearing or by tension; and the very interesting diagrams that Mr. Garbutt has prepared show the real nature of the two kinds of fracture which occur in structures of this kind. When you put a compressing load on a vertical pillar of that kind there is a crushing stress on all transverse sections; but there is also simultaneously a shearing stress which is at its maximum on planes inclined at forty-five degrees to the axis of the pier, and a lateral tension on the vertical sections of the pier. If you put a vertical load upon the pier you produce a diagonal shear and a lateral tension. If the structure is one that has special vertical planes of weakness like the joints in a pier which has not been built very long, then the crushing load develops vertical fissures, due to the tension acting horizontally. If the pier does not give way at those vertical planes of weakness, then it gives way along the planes inclined at forty-five degrees to the axis by shearing. I have here a couple of bricks showing exactly a typical failure by shearing in a quite homogeneous block. Another, you see, has given way by shearing at planes of forty-five degrees to the axis. When we come to test the piers which are older, and in which the cement and mortar will have set more thoroughly, I think we shall have more complete examples of shearing, and fewer examples of tearing by lateral tension.

MR. H. F. DONALDSON, M.Inst.C.E., Chief Engineer of the London and India Dock Joint Committee.—Sir, the Papers we have heard are to us most instructive and most interesting. With regard to what Professor Unwin said, that in testing his cement he did not consider it necessary or of importance to test for tension—he tested simply for compression—it appears to me, by the example he showed us with a brick, that tension is very necessary in arriving at some data of the material used in the construction of the piers. I noticed one or two points when I was down at the scene when the piers were being broken. In the first place, it was

not, I thought, weather for such work at all; it was extremely cold, and I think the Institute owes a great debt of gratitude to the Committee for standing it out. Another point is the enormous difference which exists as between the crushing strength of, say, Leicester Reds in the brick itself, which is stated to have stood 382 tons per square foot, and the results shown in the bricks when they are in the form of a pier. I think the highest of the Leicester Reds was about 67 tons, which finally failed by bending suddenly: this seems to me to point to the tensional strength of the cement, or lime, or whatever it was that was used, being taken into account as well as the crushing strength.

MR. P. GORDON SMITH [*F.*].—Sir, we owe a great debt of gratitude to Professor Unwin for the very valuable help he has afforded us, as well as to those gentlemen who have spent so much time in looking after the conduct of the experiments. These experiments have been conducted up to the present time on piers which are only some three or four months old, and I shall attach a great deal more importance to the experiments when the piers have attained the age of nine or ten months. But I must remind members that these experiments can only be carried out if money is forthcoming, and I hope that liberal support may be afforded to us in the shape of subscriptions, to enable the Committee to carry on the experiments to a satisfactory conclusion. Although these experiments are in the early stage of progress, I think we cannot pass over the present occasion without offering our cordial thanks to Sir William Arrol for his help in giving us the opportunity of using a powerful machine for testing these large masses of brickwork; and I should also wish to ask you to thank Mr. Donaldson for his help in affording us the facilities we have had at the Docks.

MR. JOHN SLATER [*F.*], B.A.Lond.—Sir, I believe Mr. Gordon Smith, as one of the Science Committee, was unable, or through modesty did not like, to include in the vote of thanks which he suggested this Meeting should pass to Sir William Arrol, Mr. Donaldson, and others, the thanks which we certainly owe to the Committee for the trouble they have taken in carrying out these experiments; and I think more especially for giving us here these lantern illustrations of the piers, for there can be no better way possible of showing views of the experiments to a meeting like this. The photographs taken will also, if I may say so, be a standing monument to the assiduity of the members of the Committee. There are one or two very curious things with regard to these experiments. We were always, of course, under the belief that from about two to four tons, as Professor Unwin said, was a safe load on brickwork; and I am bound to say I cannot help thinking that some element of error has crept into that general table of results when you look at the Gault bricks, because it is a most extraordinary thing that the final failure of the Gault brick piers with mortar is higher than in the case of cement—it is 21·82 in mortar and 17·98 in cement. I cannot understand that at all, because there can be no possible doubt that cement is stronger than mortar, and in nearly all other cases you find that the piers of cement carry a much greater load than they do in mortar. I should be very glad if Mr. Street or some one else could give us some explanation of that very curious fact. And in addition there is a very small difference between the load at which partial failure is shown, or rather, I should say, at which the commencement of failure occurred. The average of the two Gault brick piers I make out to be 5·54 in mortar and only 7·08 in cement; so that I for one should be very glad to have a little more information on that point. I do not know whether the Gault piers had—perhaps it is a fact that they had—some bricks in the interior that were not of Gault quality, and that may have vitiated the results; but I think it would be well not to publish, as a final statement, the data as to those piers till you have had an opportunity of re-testing them in cement, and especially at the end of a longer period; because it is clear, from the experiments Professor Unwin has made, that both cement and mortar increase in strength with age. There is another very interesting point to which he has alluded, and that is the fact that a half-brick will not carry per inch or per foot super. so much as a whole brick; and he states the reason of it very clearly, because he says the crushing pressure diminishes as the ratio of height to horizontal dimensions increases. Now that, I think, has a more general practical bearing than the mere statement of it would seem to imply; because if that is the case, are we not making a mistake in practical building if we put under heavy girders or columns, or anything of that sort, a thicker stone template than is really wanted? If it is really the fact that the final crushing pressure diminishes as the ratio of height to area increases, then there must be one point at which we can get our strongest template; and if we increase the thickness of it afterwards in a homogeneous material like stone we do harm rather than good. I would suggest to Professor Unwin what an exceedingly valuable series of experiments he might make at the Central Technical College if he would take a square piece of stone, such as York stone, two inches thick, and one of an exactly similar area four inches thick, and try the effect of his 100-ton machine on them. I have great pleasure, Sir, in seconding the vote of thanks to Sir William Arrol and the other gentlemen who have given their assistance; but I am sure that the Institute would not like to leave out of the vote the Committee who have taken such trouble and brought these results before us so plainly and concisely to-night.

THE HON. SECRETARY.—Sir, would not

weight placed on these piers suddenly, or nearly so, by the hydraulic machine give an entirely different result from what would occur in actual building, where the load would be gradual?

MR. BERNARD DICKSEE [*A.*].—Sir, Mr. Slater has called attention to the fact that the Gault piers in cement failed at a lower figure than in mortar. That was actually so, and that is the real reason why we are rebuilding those two piers. It was generally observed in the case of the cement piers that they did not begin to fail till a much higher weight in proportion to the breaking weight than in the case of the lime piers, the lime piers commencing to fail at less than half the total breaking weight. All the piers failed, more or less, along the line of closure, showing that the way in which we generally build 18-inch piers with two closers is about the weakest form we can adopt. If we analyse these piers we shall find that there are nine columns of half-bricks, nine solid columns $4\frac{1}{2}$ inches square, one at the corner and middle of each side, and one in the centre of the pier, and the remainder is taken up in one course or the other by closers. Now, in bricks, particularly hard bricks, it is a matter of impossibility to get the closure theoretically correct. It should, of course, be a brick split down longways, but that is never the case: it always consists of two quarter-bricks, and the result is that in the piers there is from top to bottom at each corner a vertical fissure of $2\frac{1}{4}$ inches by $2\frac{1}{4}$ inches; so that really we have taken the weakest form of brickwork upon which to experiment. Mr. Max. Clarke has suggested that we should experiment upon a length of wall wherein the closers will not form such a large factor; but that is a matter of funds, and funds have not been forthcoming as our Committee think they should. If there are any present here to-night who have not subscribed to our fund, I trust that, having seen the valuable results we have so far obtained, they will not leave this room without so doing. Mr. Street, or Mr. Searles-Wood, or any other member of the Committee would be very glad to collect the names of those willing to give their guinea. I should like to mention in conclusion that the Committee have also had very valuable assistance from Mr. Dibdin, chemist to the London County Council: he, at my request, transmitted through Mr. Blashill to him, has prepared a careful analysis of the mortar used, after we had experimented upon it. His report will be published along with this Paper, and I propose that this Meeting pass a hearty vote of thanks to him.

PROFESSOR AITCHISON [*F.*], A.R.A.—Mr. Vice-President and Gentlemen, a great part of my early professional life was spent in building and in surveying heavy structures, mainly warehouses, in which the strength of brickwork was a very important factor. In most cases the brick piers had failed from overloading, for, when pressed for room, warehouse-keepers will almost double the load allowed rather than send goods away; but sometimes from the improper bedding of the C.I. plates for columns on the bases of stanchions. One of the obligations that we are under to the Committee, to Professor Unwin, and to the other gentlemen who have helped us, is the information they have given of what piers will bear within a few months of their erection, and especially those in mortar. Loading piers or walls before they have had time to properly set I look upon as being one of the greatest sources of failure. How long it takes to thoroughly set the mortar in the centre of a pier of 18 inches or 2 feet 3 inches or 3 feet square I do not know, but it must be the work of some years, because so soon as the outer surface of the mortar has set, the probability is that the air enters less freely into the body of it, and therefore the inside mortar takes a long time to set; and most of the failures that I have noticed have been in piers loaded shortly after they were built. In warehouses such piers are mostly on the ground or basement floor, and take heavy weights. Hardly has the warehouse been roofed in when the owners, being pinched for room, fill it full of goods. You see, therefore, it would be a most important thing for us to have some approximate idea of what the strength per square foot of piers built in mortar would be when the face joints only were set; also the time it would take for the wall to be thoroughly set throughout, and what the brickwork would then bear per foot superficial. I recollect seeing a pier 2 feet $7\frac{1}{2}$ inches by 1 foot 6 inches which bore a girder flush with its 2 foot $7\frac{1}{2}$ inch face, which buckled, and the bricks of its face were crushed with a weight of $2\frac{3}{4}$ tons to the foot superficial. The pier was of stocks set in mortar gauged with cement, not over-well executed, and loaded as soon as the face joints had set. I had a good many experiments made on 9-inch cubes of brickwork in cement, both of London stocks and Malm paviors, as well as they could be made in my younger days. The crushing weight I paid very little attention to, for the cracking weight is the first sign that the material gives of being loaded with more than it can bear.

All cubes set 8 months before being crushed, and crushed between No. 2 $\frac{3}{4}$-inch spruce boards.

No. 5 9-inch cubes of Malm paviors in cement and sand:—

Average weight, 42·2 lb.
Average cracking weight, 14·2 tons.
Average crushing weight, about 38 tons.
Average cracking weight per foot superficial, 25·2 tons.

No. 6 9-inch cubes of London stocks set in Portland cement and sand:—

Average weight of cubes, $42\frac{1}{2}$ lb.
Average cracking weight, 17·66 tons.
Average crushing, 44·83 tons.
Average cracking weight per foot superficial, 31·3 tons.

The piers, 18 inches square and 6 feet high, the Committee experimented on certainly showed a most extraordinary falling off from my experiments, but the two queen closiers were doubt-

less a great source of weakness, only they were inevitable; it should open our eyes to the loss of strength in built brickwork, and would be a much greater loss of strength in ordinary work. When we are using Staffordshire bricks we should have the king and queen closiers made. Our friends the engineers, who have done such marvellous works in iron that they have filled the world with astonishment, are constantly on the look-out for all the particulars that are wanted for carrying their works to perfection, so we must look to them for almost all the knowledge of materials we are to get. Doubtless they will not overlook the time it takes to have brickwork, even in cement, arrive at its greatest strength. There is one great difficulty in the use of cement, that it will not bear fire. Brick piers under fire fly to pieces; therefore there is great advantage in the use of mortar for us who build, we hope, for all time. I have now to thank the Committee for all the trouble they have taken, and Professor Unwin and the other gentlemen who have been so kind as to lend us their aid.

MR. F. WALKER, Clerk of Works, author of *Brickwork*.—Sir, I noticed one thing in particular which has already been referred to, that is, that the line of least resistance is in the line of closure; and another thing struck me very forcibly, namely, the greater results in the 14-inch pier as compared with the results in the 18-inch pier. I have just reckoned up that in the 14-inch pier you reduce the area of the 18-inch pier by one-fourth, and you reduce the vertical joint by two-fifths; and it struck me that the number of joints in your brick piers might very considerably have something to do with the strength of the pier. It has also struck me as remarkable that your piers in all cases, with one or two exceptions give way in the line of closure. It also struck me that the gentlemen experimenting on these piers and fractures in the line of closure did not suggest another method of bonding. Now, I was in the United States for five years, and I noticed there that the bond of brickwork is very different from what it is here. It is only on engineering works that they adopt the old English bond; but generally the bond is a $4\frac{1}{2}$-inch bond, which brings heading courses running through in some cases into the third or fifth course; and I have actually known them run as many as eight stretching courses throughout a building to one heading course. In England we must all have noticed when we have a fracture in a wall that it is always in the transverse direction, in the direction in which you get the most joints. I should like to suggest to the gentlemen making these experiments that they should run two courses in the piers $4\frac{1}{2}$ bond, and each third course a heading course; also that they should run five courses $4\frac{1}{2}$ bond, and every fifth course a header. I do not know what the result would be; I am only with your permission throwing that out as a suggestion. No doubt you are all aware of that bond known as the Dutch bond, by which means you do away with the closer and work your coign with whole brick and every alternative course three-quarters of a brick, starting from the three-quarters brick with a header, so that you do not have that weakness which is introduced in your piers by the closer. One gentleman remarked upon the results obtained from the sand used by the test being double that attained on the building, which he attributed to the presence of earthy matter in the sand. I would like to suggest that the size of the particles may have something to do with the strength of the resulting mortar, especially with cement; because it seems to me that if you have very small grains of sand your cement has more work to do in causing those numerous grains to adhere in the mass than it would have to do if the grains were somewhat larger. With respect to American bricks, I can also testify that they are infinitely better and much harder as a rule than English bricks. One speaker has suggested $9'' \times 9''$ bricks. I would simply like to remark in that connection that it would add considerably to the cost of the brickwork; that instead of getting the proverbial 1,000 a-day laid by the bricklayers (and I am prepared to say that you more generally get 600), I think you would get very much less, and would add infinitely to the cost.

THE CHAIRMAN.—Gentlemen, the Science Committee have fortunately initiated this work of testing the value of bricks and the strength of bricks and brickwork in various forms, the experiments being preliminary to a larger series which they hope to make by-and-by if the money comes in. I hope they will receive every pecuniary assistance, and be able to continue the work they have begun so well. This is one of those happy instances where architects and engineers, and distinguished authorities like Professor Unwin, co-operate for the common good. I know we as architects are indebted very much to engineers for many things; we are indebted for those elaborate formulæ and tables so familiar to us when we want to know the strength of a wrought-iron girder, or the strength of a column to support a girder or a wall. But now we architects hope to assist the engineers; and in the matter of testing brickwork our Science Committee are going to add to our amount of knowledge on the strength of materials. In the course of time, I have no doubt we shall have a very valuable text-book on the subject; and it is very gratifying to me this evening to propose to you the vote of thanks, which has been moved by Mr. Gordon Smith and seconded by Mr. Slater, to Sir William Arrol, to Mr. Donaldson, and to Mr. Dibdin; to Mr. Wonnacott for his photographs; and last, but not least, to the Science Committee, with especial mention of Professor Unwin for his kind co-operation in the conduct of these experiments.

9, Conduit Street, London, W., *2nd April* 1896.

CHRONICLE.

THE MIDSUMMER EXAMINATIONS.

The Progressive Examinations, ultimately qualifying for candidature as Associate, are held this year in the month of June, as follows:—

Preliminary Examination, to qualify for registration as *Probationer*: 16th and 17th June.

Intermediate Examination of *Probationers*, to qualify for registration as *Student*: 16th, 17th, 18th, and, if necessary, 19th June.

Final Examination of *Students*, to qualify for candidature as *Associate*: 26th June to 4th July inclusive.

All the above-named Examinations will be held, in London, at the Examination Hall, Victoria Embankment; and, simultaneously, both the Preliminary and the Final Examinations will also be held at provincial centres under the charge of Allied Societies as heretofore. An Intermediate Examination for Scotland will take place under the charge of the Glasgow Institute of Architects, provided not less than twelve Probationers make due application to be admitted to it. This, if it take place, will be the first time the Intermediate Examination has been held out of London.

A special Examination qualifying for candidature as Associate (subject to section 8 of the Charter), for architects in practice who are not less than 25 years of age, and for chief assistants over 30 years of age, will take place on the same days as those allotted to the Final Examination, above mentioned. This is intended for applicants exempted, by special Resolution of the Council, from the Preliminary and Intermediate Examinations, and from submitting Testimonies of Study. An applicant not in the active exercise of his profession previous to 1st January 1885 is expected to submit Probationary work, which may consist of the working drawings of a building, executed or otherwise, of his own design, with a perspective view (not necessarily of that building) and a drawing of some ornament from the round.

By a recent regulation, in force since the 1st January 1896, applicants admitted to any of the three Progressive Examinations, or to the Special Examination, who are unsuccessful at their first sitting, may present themselves a second time without a further fee; but should they then fail to pass, a fresh fee must be paid for each subsequent attempt.

The Final Examination: A New Prize.

Mr. Arthur Cates proposes to give a Prize of Books (value ten guineas) to the *Student* who submits the best Testimonies of Study for admission to the Final Examination and who passes it. The Prize is open to competitors among the Students R.I.B.A., at both the Final Examinations annually held, and the first of these competitions will take place this June. Fuller particulars of Mr. Cates's gift will be found in the following letter addressed on the 14th ult. to the Secretaries:

Dear Sirs,—The preparation of the Testimonies of Study required to be submitted to obtain admission to the Final Examination is of so high an educational importance that the standard of execution should be good. With a view to encourage some little competition in the production of these "Testimonies," and promote the attainment of a high standard in their execution, I will give ten guineas (£10. 10s.) as a prize to be expended in books suitably inscribed, to be awarded at each Examination to the candidate whose Testimonies of Study shall be considered by the Board of Examiners to best merit such prize, on condition that such candidate pass the Examination, on the occasion to which he has been admitted. Should he fail to pass, the prize to be awarded to the candidate next in merit with his Testimonies who may have passed satisfactorily, provided that the Board are of opinion that the Testimonies are of such quality as to merit the prize. As this prize is offered for each Examination, and only for excellence in the preparation of the Testimonies, it is not likely to clash with the Ashpitel, which is only awarded once in the year, and then for general excellence, though happy will be he who may succeed in winning both. I hope that when this is communicated to the Students it will encourage them to endeavour to attain excellence in the production of the Testimonies.—Yours faithfully, Arthur Cates.

The Council, when accepting this offer, made, as they felt, in the interests of professional education, expressed their high sense of its value, and ordered a resolution of thanks to be recorded in the Minutes of their proceedings.

Mr. Penrose and the Parthenon.

The President, whose then imminent arrival at Athens was announced in a London paper of the 16th ult., has evidently taken Time by the forelock in his congenial task of once more climbing the Parthenon. *The Standard*, in its issue of the 30th ult., states that Mr. Penrose has taken "new "measurements of the ancient edifice, and has "discovered, to his surprise, that the preserved "portions of the Temple have remained without "the slightest change since he first investigated "the structure fifty years ago, when he made "those original researches which have long been "familiar to the students of Greek antiquities "throughout the world. In conformity with "the advice of Mr. Penrose, the work of rendering "the entablature solid and secure is soon to be

" commenced." An extract from a letter dated 19th ult., from Mr. Charles Clarke, who has gone out to measure and make drawings at the excavations now being carried out by the British School at Athens, may be also of interest to members: " Mr. Penrose, who arrived two days ago, has " been delightfully clambering all over our ex- " cavations . . . with boyish activity in between " his other important engagements. I am to have " the privilege of assisting him to take some mea- " surements (on the top, I think) of the Parthenon " to-morrow morning at 8.30." The letter was addressed to Mr. R. Phenè Spiers.

The late Emile Boeswillwald [*Hon. Corr. M.*].

The death of Emile Boeswillwald, on the 20th ult., is an event of much greater importance than the majority of architects in this country and even in his native land are probably prepared to admit. The Royal Institute of British Architects is especially favoured with a notice of the deceased Master from the pen of Monsieur Antonin Proust, a former Ministre des Arts in Paris, and well remembered by those Englishmen who had the honour of meeting him in his official capacity at the International Exposition of 1889. M. Proust writes from Paris, 26th ult., as follows :—

M. Emile Boeswillwald, qui vient de mourir à l'âge de quatre-vingt et un ans, était architecte de la Commission des Monuments Historiques depuis plus de quarante ans. Il était né à Strasbourg le 2 mars 1815, avait suivi les cours de M. Labrouste et était entré à l'Ecole des Beaux-Arts le 29 décembre 1837. A l'Exposition de 1849 il avait obtenu une médaille de deuxième classe, et dès ce moment Prosper Mérimée se l'était adjoint dans ses tournées d'inspecteur général des monuments historiques de la France. Le 12 août 1853 il obtenait une médaille de première classe, et en 1865 il était nommé architecte de la Sainte-Chapelle, inspecteur général des monuments historiques et inspecteur diocésain des départements des Basses-Pyrénées, d'Eure-et-Loir, et de la Sarthe.

M. Emile Boeswillwald a été avec Lassus et Viollet-Le-Duc un des artistes qui ont le mieux étudié et le mieux compris l'architecture du moyen-âge. D'une modestie très grande il n'a jamais fait état des innombrables travaux qu'il a conduits avec une sûreté de vues et une science de la construction qui lui réservent une des premières places parmi les restaurateurs de notre architecture nationale.

La Bibliothèque des Monuments Historiques possède de lui des travaux admirables : 1° la restauration de la Chapelle d'Elsach en Bavière, faite en 1839, six dessins ; 2° les ferrures de la Porte Saint-Marcel de Notre-Dame de Paris, façade occidentale, deux dessins ; 3° études sur les monuments chrétiens de la Picardie ; 4° fragments d'étude sur une restauration de l'ancienne Abbaye de Saint-Germer (architecture, peintures, vitraux), fin du XIII^{e} siècle, cinq dessins, 1842 ; 5° dessin de la Porte Sainte-Anne à l'église Notre-Dame de Paris, 1844 ; 6° projet de restauration de la Cathédrale de Laon ; 7° église de Niederharlach (Bas-Rhin), trois dessins ; 8° église de Neuviller (Bas-Rhin), deux dessins ; 9° église de Moutier en Der (Haute-Marne), quatre dessins ; 10° église de Gulviller (Bas-Rhin), quatre dessins ; 11° palais des ducs de Lorraine à Nancy, deux dessins.

L'autorité de M. Emile Boeswillwald dans la Commission des Monuments Historiques dont il était le doyen était telle qu'il y a deux mois, lorsqu'il résigna ses fonctions d'inspecteur général des monuments historiques qui furent confiées à son fils, M. Paul Boeswillwald, professeur à l'Ecole des Beaux-Arts, la Commission par un vote unanime demanda que M. Emile Boeswillwald fût nommé inspecteur général honoraire. Jusqu'au dernier jour de sa vie notre ami a pris part aux travaux de la Commission, écoutant avec une émotion visible les rapports que son fils lisait et dans lesquels il s'inspirait des belles traditions que lui a léguées son père.

C'est à l'enterrement de la mère de M. Formigé, l'un de ses collègues, qu'il contracta le refroidissement qui l'a enlevé. Et le jour de ses obsèques, le petit appartement d'Emile Boeswillwald, au quatrième, était à ce point encombré de ses amis que le plus grand nombre n'y put trouver place et dut se tenir dans l'escalier.

Jamais l'Institut de France n'a eu la pensée d'admettre Emile Boeswillwald au nombre de ses membres, et cependant l'œuvre de ce maître survivra à celle de beaucoup de ses confrères ; et il y aura longtemps que leurs noms seront oubliés que l'on honorera toujours ce serviteur scrupuleux de notre art national.

According to *La Construction Moderne* (28th ult.), which has an excellent article on the late Master, Boeswillwald was the son of a baker, and apprenticed to a contractor of " Maçonnerie," under whom he learnt the art of building in stone, moellons, bricks, plaster, &c. He spent the year 1836 at Munich, working, it is said, on the classic buildings then in course of execution for King Louis of Bavaria. Thence he came, by way of his native city, Strasbourg, to Paris ; and there entered the " Atelier " of Labrouste, in which he found a fellow-citizen named Klotz—who was for thirty years architect to Strasbourg Cathedral—and Lassus, the predecessor and contemporary of Viollet-Le-Duc in the charge of various important historical monuments. His real master, it is also said, was Lassus, under whom Boeswillwald was " Inspecteur " in 1845 at Notre-Dame, Paris ; and his most important works of restoration, in which he showed himself superior to all his French professional brethren, were the cathedrals of Chartres,

Bayonne, and Laon. At the last named, in 1874, he received the members of the Architectural Association, who, under the guidance of Edmund Sharpe, visited some of the chief cities of the North of France—reaching Laon in haste from the South, where he had been staying, and displaying immense activity in his desire to explain to the excursionists important points of interest in the Cathedral. Indeed, after that, no one was more enthusiastic in praise of Boeswillwald (who, *pace* French susceptibility, spelt his name with three l's, not two) than Edmund Sharpe; and the latter, with Mr. Penrose, proposed him as Hon. Corresponding Member, his election having taken place on 1st February 1875. Five years afterwards the Imperial Academy of Vienna accorded him a like recognition. But, as M. Proust warmly regrets, the Académie des Beaux-Arts, treating him as it had previously treated Viollet-Le-Duc, closed the doors of the Palais de l'Institut against him.

That he was always simple and unaffected, always charming in phrase and manner, as when he wrote in 1880 refusing a Paper on his restoration of Laon Cathedral, and as he was the same year at Bayonne when he conducted two English confrères over the cathedral of that city, his friends at a distance know full well; that he was the personification of the Mediæval Master-of-the-Work, whether *en blouse* in his Paris studio, when he laid before you working drawings of the latest building he had in hand, or *en grande tenue* as a visitor to the International Exposition of 1889, none who knew him and his career can deny. It was to many a great disappointment that Boeswillwald was not present at the Banquet of the Société Centrale on the 7th ult., and expression was given to the regret felt at his absence from a function of such interest to all who took part in the proceedings.

The great work on St. Mark's, Venice.

The Library has been enriched by the addition of Cavaliere Ferd. Ongania's remarkable monograph, entitled *La Basilica di San Marco in Venezia*. This exhaustive work, the fruit of ten years' unremitting labour, finally completed in 1888, comprises four volumes of text (three folio and one quarto) and five portfolios of illustrations. A glance at the contents may give some slight idea of the scope and magnitude of the editor's task. The first volume includes a series of Essays on the Legends and Historical Records relating to the Basilica, the Jurisdiction of the Doge, the Procurators of St. Mark, the Holy Office, the Deans, Ancient Rites and Ceremonies of the Church, and the Choir. In the second volume is given the architectural history of the Basilica from its early Byzantine period to the close of the sixteenth century. In the third volume are described the pavement, the crypt, the symbolical sculpture, the statues from the fourteenth century down to comparatively modern days, the enriched columns which support the ciborium, the mosaics and inscriptions, the various marbles used in construction or for decorative purposes, the metal-work, wood carvings, and *tarsia*, the famous bronze horses which adorn the façade, and the works of restoration carried out at St. Mark's within recent years. The fourth volume, a quarto, contains extracts printed in fac-simile from ancient chronicles and public records bearing on the history of the Cathedral. A summarised translation of these documents is given in English. The illustrations in Portfolio I. include geometrical elevations, plans, and sections of the Basilica in twenty-seven plates, folio. Portfolio II. contains chromo-lithographic views of the building and enlarged details in forty-five plates of folio size. Portfolio III.: details of the mosaic subjects (not included in the geometrical illustrations)—sixty-eight plates, quarto. Portfolio IV.: details of the pavement and mosaic decoration of the vaults and windows of the five cupolas—sixty-eight plates, quarto. Portfolio V.: the figure sculpture and decorative carving of the church (exterior and interior), the altars, amboni, archivolts, capitals, cupolas, monuments, and sepulchral inscriptions, bronzes, inlaid work, &c., in 425 plates, quarto, heliotyped from the actual objects. This work was dealt with in a review by Mr. Charles Eastlake in *The R.I.B.A. Journal*, Vol. V. N.S. p. 9.

NOTES, QUERIES, AND REPLIES.

SOUND IN ITS RELATION TO BUILDINGS.

Proposed Experimental Research.

In the discussion of the Paper, by Mr. H. W. Burrows [*A.*], on "Sound in its Relation to Build-"ings," published in the second volume of the present series of the JOURNAL [p. 353], Professor Roger Smith urged that experiments should be made on the subject and the results recorded. To some extent, said the Professor, every building was more or less an experiment. If the Science Committee would secure a collection of observations upon interiors, their dimensions, their materials, whether they were successful for music, whether they were successful for speaking, &c., such observations, if tabulated with regard to a considerable number of known buildings, would throw light upon what was undoubtedly an obscure subject when applied to practice. Professor Banister Fletcher supported the suggestion, and other speakers who joined in the Discussion urged the desirability of making further inquiries and tabulating facts. This the Science Standing Committee, with the concurrence of the Council, now propose to undertake, and they have drafted, for the purpose, the following questions:—

1. *Plan.*—Give a general plan, with elevations and sections, of the *interior* of the building.

2. *Materials.*—Describe the materials of which the building is constructed, carefully noting the finish of the interior surfaces and the disposition of carpets, hangings, or other similar fabrics.

3. *Construction.*—The construction of the building should be described as fully as possible.

4. *Seating.*—Illustrate the method of seating by plan and section.

5. *Speakers, &c.*—Show position of speakers or musicians in relation to the audience.

6. *Effect of Audience.*—The effect of an audience should be carefully noted. State if the room is better when partially or entirely filled.

7. *Ventilation.*—Describe in some detail the system of ventilation. If possible, note the mean and extreme temperatures and the effect of the variation produced by it and by changes in direction of the ventilation. State the position in which the thermometers are placed. (For full explanation as to the value of these observations, see "Sound in its Relation to Buildings," JOURNAL of the Royal Institute of British Architects, Vol. II. Third Series, p. 353.)

8. *Keynote.*—If the keynote of the building is known, state it, and say whether or not, if the voice is pitched in this key, any improvement in sound is noticeable.

9. *Quality of Sound.*—(*a*) State what is the general reputation of the building for (1) Music; (2) Speaking.

(*b*) State what the quality of the sound is—full and resonant, &c., and note any peculiarity of effect, such as echoes and the like.

(*c*) If defective, state the nature of the defect as carefully as possible.

10. *Remedies.*—If remedies have been tried to obviate defects, state them, and the result obtained. The precise nature of the remedy should be fully detailed.

11. *Additional Particulars.*—Add any particulars not above scheduled which may be considered necessary or desirable, and state age of building.

12. *References.*—Give references (if any) to published descriptions of the building, especially those dealing with its acoustic properties.

13. *Authority.*—Give the names of the experimenters and date of experiments.

The Science Committee ask members to reply to the above questions, and for purposes of classification request that their observations may be written on separate sheets of paper, headed with the name of the building experimented upon, and the subjects treated of. For the convenience of members and others, the questions submitted by the Committee are printed in the *Supplement* issued with this number of the JOURNAL. Answers may be addressed to the "Hon. Secretaries, "Science Committee," at the Institute.

Appeal for Funds.

The work already done by the Science Standing Committee, as the Reports, Notes, and Statistics submitted to the General Meeting of the 30th March bear witness, shows results which fully warrant further exertions. The experiments made to this date—on bricks and brickwork—must be regarded rather as tentative than as establishing absolute conclusions; and the money with which they have been made—apart from the aid freely given by Sir William Arrol and Mr. Donaldson—has been mainly provided by individual members of the Science Committee. The small fund is now not only exhausted, but liabilities have been incurred; and it is hoped, especially as experiments in another department of science are about to be commenced, that both Fellows and Associates will assist the Committee with subscriptions, however small, and enable the useful work, so well begun, to be finished to the advantage of the profession at large.

MR. PHENÈ SPIERS'S PAPER [p. 233].

Saint-Front of Périgueux [p. 324].

The distinguished author of the works entitled *L'Art de bâtir chez les Romains* (fo. Paris 1873) and *L'Art de bâtir chez les Byzantins* (fo. Paris 1883)—Monsieur Auguste Choisy [*Hon. Corr. M.*]—who has been in communication with the author of the recent Paper on Saint-Front, has addressed a letter on the subject to Mr. Spiers, which, with the writer's permission, is here given :—

MON CHER CONFRÈRE,—Veuillez m'excuser d'en être encore à vous remercier de l'aimable envoi que vous m'avez fait de votre beau mémoire sur Saint-Front de Périgueux. Le travail de De Verneilh, remarquable pour l'époque où il a été fait, avait besoin d'être révisé, et vous avez repris la question en la traitant d'une manière qui je crois sera définitive. On ne pouvait mieux mettre en lumière la chronologie des édifices trop souvent confondus sous le nom de Saint-Front; la date de la basilique à comble de charpente ne saurait plus être discutée, non plus qu'on ne pourrait soutenir l'ancienneté de l'église à cinq coupoles : toute cette discussion de chronologie est absolument lumineuse.

La discussion des influences byzantines et du rôle de Saint-Marc m'a aussi vivement frappé. Et enfin vous avez élucidé cette question de l'interprétation de la donnée byzantine du pendentif à l'aide de matériaux de pierre. Cette interprétation n'était rien moins que la création d'un type nouveau de construction, et ce type nouveau serait bien réellement propre à l'école d'Aquitaine. Voilà un ensemble de conclusions auxquelles je suis heureux de m'associer et qui jettent un jour bien vif sur une branche importante de l'histoire de l'art à l'époque romane. Permettez-moi, mon cher confrère, de vous féliciter de les avoir traitées d'une manière si lumineuse; et veuillez agréer une nouvelle expression de mes sentiments les plus cordialement dévoués. A. CHOISY.

Mr. Phenè Spiers may be justly pleased with such testimony to the value of the conclusions at which he arrived in his Paper on Saint-Front.

From PROFESSOR G. BALDWIN BROWN [*H.A.*]—

If I ask leave to say an additional word on this subject, it is not merely to discuss rival theories,

neither of which may be capable of absolute proof, but rather to point out the need of further investigation into a most interesting chapter of Mediæval architecture. The theories of De Verneilh had at any rate one merit—they fitted and explained the facts as he conceived them. Now that the facts, *i.e.* the relative dates of the domed churches of the district in question, are differently viewed, the theories are of no help, but are rather in the way, in that they check further independent investigation. There are two questions which, even after the excellent work done by Mr. Spiers in his Paper, still require elucidation. One is the origin and early history of the dome in this region of France. Mr. Spiers rejects a Byzantine origin and claims the feature as indigenous [pp. 250, 251]; yet the Périgord domes must be, one would think, connected with the Early Christian cupolas of the West, and it would be interesting to know whether any reason can be found for the revival of this form in this particular region in the Mediæval period. The other question is the position of Saint-Front in relation to the other domed edifices of the district. Considering the number of these, and the fact that they are by no means all after one pattern, one would naturally suppose that Saint-Front is only one variety of the local type. To assume that at the very end of the development of domed churches in Périgord their builders ran to the further side of Europe to copy a foreign plan seems unnecessary. De Verneilh's theory has lost the significance it possessed at first, and might now with advantage be dropped in favour of the hypothesis of a native origin for Saint-Front, as well as for the other churches of its class. The suggestion of Dehio and von Bezold seems to give the common sense of the situation. When the old Latin church was to be rebuilt, it would be most in accord with precedent for the new structure to take up the site of the old, and this it would just have done had it received the long nave of the Latin cross plan, which occurs elsewhere in the district. (Mr. Spiers holds that there is evidence of a desire to spare the old church, because it contained the bodies of saints. All the greater Mediæval churches, however, swarmed with saints, and yet they were rebuilt over and over again.) On this supposition Saint-Front is not really a Greek cross plan, but a Latin cross plan truncated; and this seems to me, I must confess, a more likely hypothesis than that favoured by Mr. Spiers [p. 325].

There remain the pierced piers. At present the only available explanation of these is that of a derivation from St. Mark's, but by themselves they would hardly avail to sustain the Venetian hypothesis. I am inclined to think that, were this hypothesis once out of the way, independent investigation would bring to light evidence of a local derivation for these features also. There are, at any rate, eleventh-century churches in Normandy where something of the kind is observable. The church of Saint-Céneri-le-Gerei (Orne) is a case in point (see Ruprich-Robert, *L'Architecture Normande*, I. pl. ix. fig. 10). Here the piers of the crossing project into the single aisle, and are pierced with a passage through into the transept. Neuf-marché (Seine-Inférieure) (Ruprich-Robert, *l.c.*, p. 58) shows something similar. These examples seem to encourage a search for the genesis of the pierced pier much nearer home than Venice.

The Domes of Aquitaine [p. 325].

From JOHN S. QUILTER [*F.*]—

I regret the tone of Mr. Spiers's remarks on this subject, as it makes it impossible for me to reply to criticisms which indicate that the writer has failed to understand the points he criticises. He has also misquoted some of my statements, so that a meaning is given to them contrary to their natural intention. I must therefore leave the matter as it stands for the impartial judgment of the readers of the JOURNAL.

The Mysterious Wreck at Nemi.

From JOHN HEBB [*F.*]—

Mr. J. Tavenor Perry [*A.*] contributed a Paper to the JOURNAL of the 5th December 1895 [pp. 77–81], on "Some Recent Discoveries at Nemi in "the Roman Campagna," illustrated by photographs of bronze mooring-rings, &c., which had been recovered from the bottom of the Lake of Nemi, near Albano, the lake apostrophised by Byron in the famous passage:—

> "Lo, Nemi! navelled in the woody hills
> So far that the uprooting wind which tears
> The oak from his foundations and which spills
> The ocean o'er its boundary, and bears
> Its foam against the skies, reluctant spares
> The oval mirror of thy glassy lake;
> And calm as cherished hate its surface wears
> A deep cold settled aspect none can shake,
> All coiled into itself and round as sleeps a snake."
>
> CHILDE HAROLD, Canto 4, clxxiii.

The Commendatore R. Lanciani [*Hon. Corr. M.*] contributes an article on the subject to *The North American Review* (February), giving an historical account of the various attempts made to explore the bottom of the lake, and the results of recent operations. It seems that, from the earliest times, there existed a legend that at the bottom of the lake lay what was proclaimed to be a ship five hundred feet long and as rich and beautiful as an enchanted palace; and more than one adventurous person, undeterred by previous failures, endeavoured to bring it to the surface.

The first regular search was made by Leone Battista Alberti in the reign of Eugenius IV. (1431–39), the second by Francesco de Marchi in 1535, the third by Annesso Fusconi in 1827, and

the last by Eliseo Borghi in 1895, which has not been completed. After describing the results of the first three attempts, Professor Lanciani quotes Nibby, who witnessed Fusconi's search and was satisfied that the supposed ship was nothing but the framework and foundations of a building which projected into the water a considerable distance from the shore. This, he conjectured from a passage in Suetonius, was built by Julius Cæsar, who commenced a villa on the shores of the lake and destroyed it when nearly finished.

Nibby's conjecture appears from recent discoveries to have been in the main correct, but from an inscription on a lead water pipe—".CAESARIS—"AUGUSTI—GERMANICI"—it seems established that the emperor who laid this pipe and presumably erected the building to which it was attached was the Emperor Caius or Gaius Caligula, the youngest son of Germanicus and nephew of Tiberius, the Germanicus *par excellence* (A.D. 37–41).

The conclusion at which Professor Lanciani has arrived is that there was a landing pier and a building of some kind upon it; and that there was a ship of modest size, lying alongside, which had followed the fate of the landing pier. He further considers that we may identify the wreck with a pier or jetty or landing-place resting on piles lined with mooring rings for the accommodation of the small boats plying in the Speculum Dianæ (as the lake was called, in allusion to the Scythian Diana or Artemis, who was worshipped in the neighbouring groves), and supporting a construction of some kind—a boat-house, bathing or fishing establishment. When the pier sank, through the collapse of the piles upon which it was built, the whole platform slid down the steep incline of the bottom of the lake to a distance of about one hundred feet from the shore. A large boat shared the same fate at the same time.

MINUTES. XI.

At the Eleventh General Meeting (Ordinary) of the Session, held Monday, 30th March 1896, at 8 p.m., Mr. Alex. Graham, F.S.A., *Vice-President*, in the Chair, with 25 Fellows (including 7 members of the Council), 22 Associates, and several visitors, the Minutes of the Meeting held 16th March 1896 [p. 327] were taken as read and signed as correct.

The Secretary announced the decease of Émile Boeswillwald, *Hon. Corr. Member*, and of George Richmond, R.A., *Hon. Associate*.

The following Associates, attending for the first time since their election, were formally admitted, and signed the Register, namely:—Lawton Robert Ford, Percy Rider Smith, and John Robert Smith.

The Chairman called attention to a complete copy of Cavaliere Ferd. Ongania's great work on St. Mark's, Venice, which had been recently purchased for the Library, and which was laid on the table for the inspection of the Meeting; and also to a copy of the late M. Alphand's Monograph of the Paris Exposition of 1889, presented by Sir Polydore de Keyser, Bart., through Mr. Graning [*F.*]. In reference to the latter work the cordial thanks of the Institute to Sir Polydore for his gift were ordered to be entered on the Minutes.

A Report of the First Series of Brickwork Tests carried out under the direction of the Science Standing Committee was read by Mr. William C. Street [*F.*], and details were described by Mr. Max. Clarke [*A.*] with the aid of photographic views shown by the lantern; further details were given in a Paper by Mr. Matt. Garbutt [*A.*]; and Professor Unwin [*H.A.*], F.R.S., made some observations on the value of the results so far obtained, and reported on his tests of samples of the materials used and on other matters connected with the experiments. A vote of thanks was thereupon passed to Sir William Arrol and Mr. H. F. Donaldson, M.Inst.C.E., for the generous aid afforded by them in the experiments; to Mr. Wonnacott [*A.*]; to Professor Unwin and the other members of the Committee; and to Mr. W. F. Dibdin.

The proceedings then closed, and the Meeting separated at 10.15 p.m.

LEGAL.

Sky Signs.

On 13th March Mr. J. Dowling, of 35, Jewin Street, appeared before Mr. Alderman Truscott, at Guildhall, for an alleged contravention of the sky-signs portion of the London Building Act. The summons was issued at the instance of the Commissioners of Sewers, for whom Mr. Vickery appeared. Mr. Barrett represented the defendant.

Mr. Edmund Woodthorpe, District Surveyor for the Northern Division of the City, deposed that there were certain skeleton letters on the roof of the defendant's premises, which he described as a sky-sign. In cross-examination he said that the sky was not visible through the letters, owing to some boarding erected behind.

The Alderman visited the place and looked at the sign, and found that the sky was partly visible through the top of the letters, but to a very small extent. He asked Mr. Vickery whether he pressed for an order. Of course, if an order was pressed for, he would be bound to make one, as a technical offence had been committed.

Mr. Vickery said the District Surveyor pressed for an order; and the Alderman made one for the sign to be taken down within the next two months.

On the same day Mr. W. Harris, 32, Bishopsgate Street, appeared to a similar summons in respect of a sky sign upon his premises. Mr. Vickery said the alleged sky sign consisted of an advertisement board outside the front part of the defendant's premises. It was a board fifteen feet high at each side and eleven feet in the centre, and extended the width of the premises. It was fixed to the party wall by very rusty iron ties, and bore an inscription, "Harris's sausages are the best."

Mr. Woodthorpe, the District Surveyor, expressed an opinion that this was a sky sign. It was not open work, and was securely fixed and not dangerous, though the iron supports were rusty. Notice had been served on the defendant in 1894, but no further action was taken till 1896.

Mr. Wildey Wright submitted that the object of the Act was to prevent dangerous structures, and it was absolutely clear that the City Surveyor did not consider this as such, else these proceedings would not have been delayed so long.

Mr. Alderman Truscott said he had carefully considered the importance of the case, and had come to the conclusion that this was not a sky sign, and that it was not dependent upon the defendant's premises for its support. It was not open to the sky, but was one continuous board. The summons would therefore be dismissed.